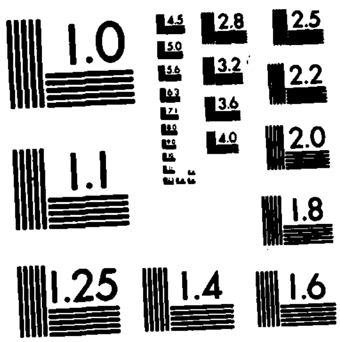
AD-A125 356 SOCIOECONOMIC IMPACT ASSESSMENT: COMMUNICATIONS INDUSTRY PHASE I DESCRIPT..(U) ACUMENICS RESEARCH AND TECHNOLOGY INC BETHESDA MD 22 JAN 79 1/2

UNCLASSIFIED FAA-APO-81-11-VOL-1 DOT-FA78WAI-932 F/G 17/2.1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Technical Report Documentation Page

1. Report No. FAA-APO-81-11 (1 of 6)	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Socioeconomic Impact Assessment: Communications Industry Phase I--Description and Documentation of the Current State-of-the-Art. Volume I		5. Report Date January 22, 1979
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address Acumenics Research and Technology, Inc. 4340 East-West Highway Suite 808 Bethesda, Maryland 20814		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOTFA78WAI-932
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Office of Aviation Policy and Plans Washington, D. C. 20591		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code APO-210
15. Supplementary Notes		
16. Abstract		

AD A125356

DTIC FILE COPY

DTIC ELECTE MAR 7 1983 S D B

83 03 04 082

17. Key Words	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 155	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

CHAPTER ONE

INTRODUCTION

Over the past century, the U.S. Society has gone through two transformations; first from an agricultural to an industrial, and now from an industrial to an informational society. One of the economic consequences of the latter transition is the makeup of the U.S. labor force. The trend towards a predominance of information workers has persisted since the 1940's and by 1975, the information workers surpassed the noninformation group [78]. According to Bell, a post-industrial society is based on services and it runs not on muscle power, or energy, but on information [7]. The information technologies - computers and communications - are key components of the technical infrastructure of an information society. As such, these technologies are expected to undergo continuing rapid development.

Civil and military aviation cannot survive without adequate supporting information technologies, which contribute to the goals of the U.S. National Airspace System (NAS): safety, economy, energy and environment (S3E). While NAS operations have benefited from the development of information technologies, a major concern also exists regarding the adequacy of NAS capacity in the foreseeable future, especially in light of the growing demand for aviation resulting partly from the recent trend of airline deregulation [21].

The situation may be described as a crisis, which implies the co-existence of opportunities and dangers. The opportunities are provided by new developments of information technologies of computers and communications. At the same time, the choice and diffusion of these new technologies must be timely and correct, for "we haven't the time for delay and we cannot afford to make mistakes" [44]. One way to cope with this crisis is to anticipate the structural changes of both the technological capabilities and the aviation needs in order to develop timely and adequate policy options.

This objective has been partly accomplished by a completed study on the impact of microcomputers on aviation [22] which was sponsored by the Federal Aviation Administration (FAA) Policy Development Division, and which has been widely disseminated to the aviation industry. The current project complements that study by focusing on the other key component of the information society's technical infrastructure - the communications industry.

I. Scope and Objectives

The current study is concerned with the forecast and assessment of communications technology, especially with respect to its impact on aviation. The study will assess the socioeconomic aspects as well as technologies *per se*. This

is due to the fact that realistic long-range forecasts must include socioeconomic structural changes such as changes in the regulatory climate. This is a significant difference between this study and the previous one on microcomputers. The different approach is necessary since the communications industry has been heavily regulated while the computer industry is not.

For the purpose of this study, "communication" is defined as any process that permits the passage from a sender to one or more receivers of information of any nature delivered in any usable form (printed copy, fixed or moving pictures, visible or audible signals, etc.) by means of any electromagnetic system (electrical transmission by wire, radio, optical transmission, guided waves, etc.) [69]. Emphasis will be placed on those processes which either directly or indirectly support the NAS operations, including air-to-air, air-to-ground, ground-to-air, and ground-to-ground communications.

The time horizon of this study will be 2020 A.D. This long time horizon has been chosen in view of the historical time delay in the diffusion of aviation communications technology. Thus, although the forecast is intended for in-place technologies to the year 2020, the forecast of the relevant state-of-the-art technologies will be only to cira 2000.

The project, for a two-year duration, is expected to accomplish the following objectives:

- To forecast the state of the art in communications technology to the year 2000;
- To forecast the diffusion of these developments into generic aviation communication systems to the year 2020;
- To assess the impact of the forecasted aviation communications system developments; and
- To develop a set of policy options which may be appropriate for FAA implementation.

II. Framework and Five Phases

We are living in a technological society. Technology is both influenced by social values and affects social behavior. Thus, technology cannot be forecasted and assessed in isolation from the social context. This study, like a number of long-range technology forecast and assessment studies [22,6] will embed the communications technology forecast and assessment in alternative future scenarios, as shown by the framework in figure 1.1.

The ultimate objective of this study is to aid policy development by the FAA. As a federal regulatory agency, the FAA has the authority to make policies which will greatly influence aviation communications but is likely to have little effect in some other areas. The alternative future scenarios, of which aviation activities are but a part, are largely determined by social values and future events which the FAA

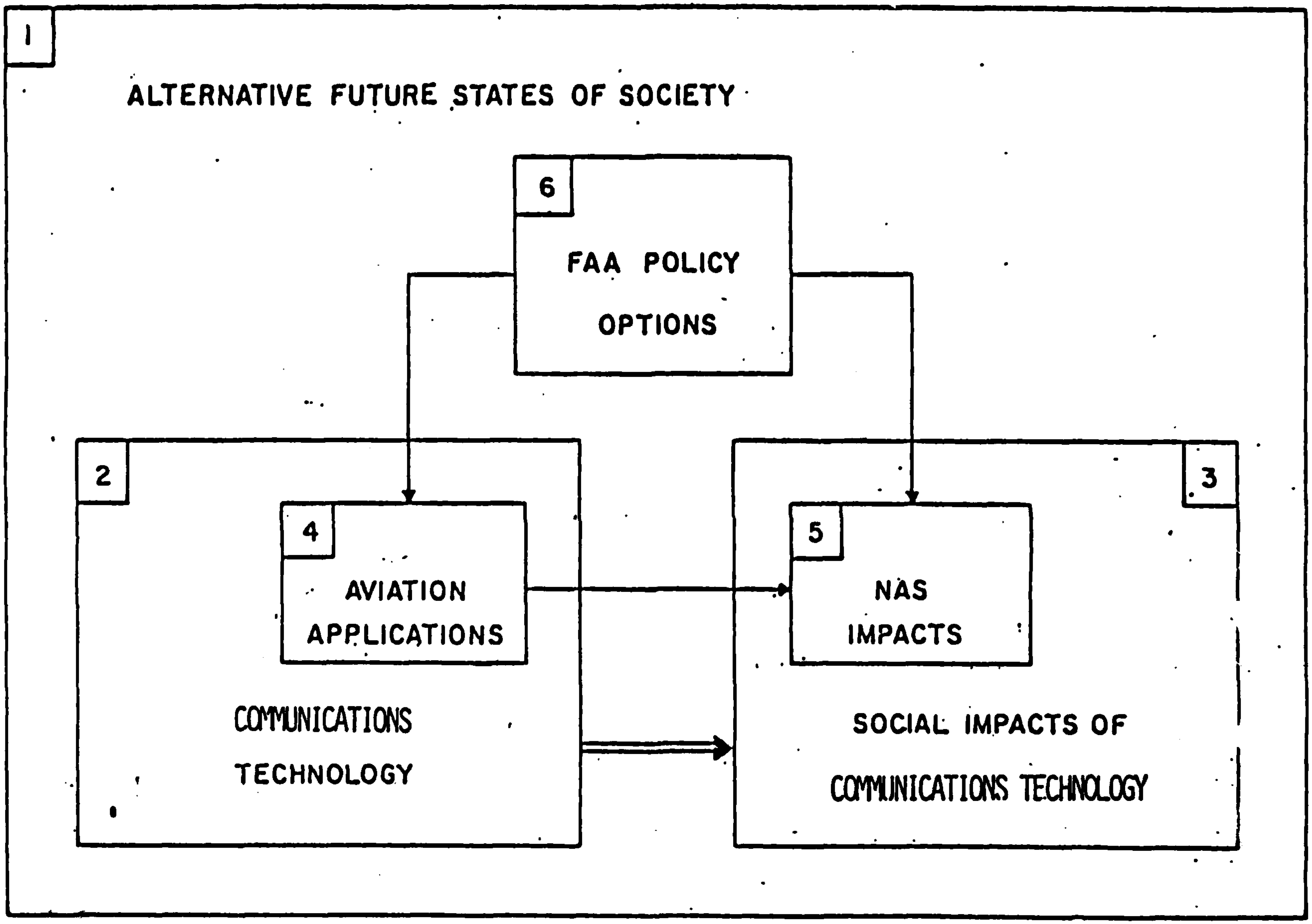


FIGURE 1.1 - Conceptual Framework of the Technology Forecast and Assessment Study

cannot influence, as shown in Figure 1.1. What can be affected by FAA policies will be the adoption and diffusion of communications technology to aviation communications, and the corresponding impacts of the latter on the National Airspace System. To accomplish the previously stated objectives within this framework, the study is divided into the following five phases.

Phase I: Past and Present Aviation Communications

The objective of Phase I is to establish a basic understanding of the history, the current status, and the near-term future (1985) of aviation communication. The future will be projected on the basis of the current momentum of aviation communication systems in the United States. This report, which culminates Phase I, also presents a categorization scheme chosen to bound the forecast and assessment of a few generic types of aviation communication systems. The historical perspective has been developed in order to gain an insight to the impacts of current and past aviation and communications regulatory regimes on the innovation and diffusion of the technology to be forecasted. This qualitative insight will be used to guide the quantitative forecasts in Phases II and III.

Phase II: State of Society Assumptions

The purpose of Phase II is to construct several alternative

future scenarios, which will provide the social context for aviation communications technology forecast and assessment. The guiding principle for scenario construction will be "range and consistency". Admitting that the future cannot be predicted with certainty, a wide range of plausible scenarios will be used to help FAA's contingency planning, and each scenario will have a level of internal consistency in order to be credible. Each scenario will include a sufficiently detailed description of such factors as aviation demands and regulatory measures, which may affect future needs and capabilities for aviation communication systems.

Phase III: Technology Forecasts

The objective of Phase III will be to forecast developments in communication technologies from the present until the year 2000. Developments in three categories of communication devices will be considered: (1) End-station input-out devices, including video terminals, hard-copy receivers, and voice-only devices; (2) Switching, formatting, and routing devices, including electronic concentrators, electronic switches, alternative message formats, companders and other Very Large Scale Integration (VLSI) telecommunications, hardware, software developments, and networking; and (3) Transmission systems and media, including cables, microwave circuits, waveguides, optical fibers, coding and decoding, spread spectrum techniques, antennas, and

communication satellites. These unconditioned forecasts will be based on a combination of engineering principles, literature review, and interviews with people in the communications industry. The conditioned forecasts (forecasts conditioned by alternative future scenarios) will include the impacts of socioeconomic conditions, especially the future regulatory climate.

Phase IV: Impact Assessment

The objective of Phase IV will be to identify and assess both the direct and indirect effects of forecasted communications technologies on aviation. The work will include the conceptual design of a few generic aviation communication systems, for each of the categories defined in Phase I. Emphasis will be placed on those impacts of the generic systems which have significant FAA policy implications. Interviews with knowledgeable experts and parties at interest, literature review, qualitative analysis of impact trends, structural modeling techniques [66] and quantitative computer models will be used in this Phase. Attention will be given to the distributive and transitional costs and benefits from the perspectives of different aviation sectors and interest groups, as these diverse perspectives may be relevant to FAA policy development. As in conditioned technology forecasts, the impact assessments in Phase IV will be conditioned upon the alternative future scenarios developed in Phase II.

Phase V: FAA Policy Options

The objective of Phase V is to identify FAA policy options in anticipation of potential aviation communication needs, opportunities arising from technological development, and their impacts. Again, the perspective of various parties at interest will be checked through interviews. Depending on specific policy issues, the parties at interest may include airlines, general aviation, pilots, air traffic controllers, aircraft and avionics manufacturers, environmentalists and consumer groups. Where potential conflicts are anticipated, the approach of "value-oriented social decision analysis" will be taken to pinpoint their differences and to help develop policy options that may reduce their conflicts. Where uncertainties in future technologies and their impacts are a significant factor, an appropriate technology monitoring system will be recommended for implementation by the FAA.

III. Relevance of Phase I to the Entire Project

Phase I work has significance beyond that of providing a point of departure for technology forecast and assessment. In general, the longer one's forecast horizon, the more one needs to understand the historical roots, barriers, and trends of the areas in question. This is required to identify the critical forces of structural change and to avoid naive and

simplistic extrapolations. These forces are especially important for communications and aviation industries as both have been regulated, and as significant changes in their regulation are being proposed and partly implemented [61, 84]. A recent technology assessment of land mobile communications similarly began with an in-depth discussion of its historical roots and the regulatory process [9].

Operationally, Phase I will form the basis for the succeeding phases. Specifically, it will identify important factors to be included in the scenario development in Phase II. As discussed previously, Phase I includes a near-term forecast of the U.S. aviation communication system to the year 1985, on the basis of current FAA plans. Thus the technology forecast in Phase III will draw partly from the near-term forecast in Phase I. The categorization scheme chosen in Phase I will be used for the design of the generic systems (and for the assessment of their impacts) in Phase IV. Finally the critical issues surfacing in Phase I, especially those related to aviation communication technology diffusion, are expected to influence the focus of FAA policy options to be developed in Phase V. Thus, this Phase I report sets the stage for the entire project.

CHAPTER TWO

OVERVIEW OF AVIATION COMMUNICATION

Aviation communication has evolved from nonexistence in the early days of aviation to the sophisticated and indispensable role it plays in the present National Airspace System. Communication is especially important to the current operation and future improvement of the Air Traffic Control (ATC) system. Both communications technology and the ATC have gone through rapid and significant changes.

The fundamental changes in ATC could not have been accomplished without new communications technology. Yet breakthroughs in communications technology may not lead to immediate changes in ATC. Although ATC and communications technologies are interrelated, each follows its own dynamic path. This chapter discusses their historical evolutions, the interaction between their evolutions, and presents a categorization scheme for aviation communications.

I. The Changing Role of Communications in Early Aviation

The National Airspace System (NAS) includes not only the physical airspace over the United States, but also airports, navigational aids, communications, aeronautical charts, and

information, flight rules, regulations, procedures, and the necessary personnel, facilities and material to operate the system. Military systems, provided and operated for joint use or primarily military use, are included, while military operated systems, for military use only, are excluded. The Federal Aviation Administration (FAA) has the overall management responsibility of the NAS. Moreover, under international agreements, the FAA also controls airspace that extends over the Pacific and North Atlantic.

The NAS has its beginnings with the Wright brother's flight at Kitty Hawk. World War I (WWI) spurred aircraft production and also caused a much wider involvement and awareness in flying. After WWI, surplus aircraft were available for barnstorming pilots and to the newly created U.S. Air Mail Service, which pioneered commercial aviation.

In open cockpits without communication equipment, early pilots were severely hampered by weather, flew low for navigation reference, and were plagued with delays due to mechanical problems as well as weather. The whereabouts of mail flights were unknown until the pilot landed at a field with a telephone, or if forced down because of weather or mechanical problems, until the pilot established contact with the local community. Many were unknown until the wrecks were discovered.

This lack of communication and the need for weather information led to point-to-point circuits being established for the major routes. Lighting systems were developed by the Post Office Department to speed delivery of the mail by allowing night flying. This increased the landing safety as well, by defining the runway boundaries. Early light line airways consisted of beacon lights spaced along the airway such that navigation could be accomplished by flying from light to light.

With the Air Commerce Act of 1926, airway responsibility shifted from the Post Office to the Commerce Department. Airways were established with periodic emergency landing fields, light lines with spacing of about ten miles, and airport markings for both day and night operations. Also, radio telephone stations with weather information were placed along the route about every 200 miles. Radio beacons were added to the light line system to allow pilots to use radio location devices. Early devices used a "loop of wire around the upper and lower wing of an airplane" as a makeshift antenna [95].

While the radio telephone stations were established along major air routes, few aircraft had the radio equipment to use the service, and it was only effective along the east coast. Radio telegraph was used to connect important stations and relay information. Teletype was used to establish the circuits between

weather stations. As aircraft radios were improved, ground-to-air broadcasts of weather information were established, followed by two-way air-ground-air weather exchange, position reports and status information.

As air traffic grew, so did the need for more precise navigation and traffic separation. Light lines and beacons were enhanced with radio ranges that defined the route by a continuous aural cue. With this information and a barometric altimeter, traffic separation was possible using air-derived navigation data and assigned altitude. However, navigation and location accuracy was still low.

Improvements in the aircraft and to ground communication devices continued during the 1930's. Low frequency (LF) marker beacons were added to define the "over-the-station" position. These were later replaced by 75 MHz marker beacons which activated a marker light in the cockpit. Radio compasses were developed with steering indicators that later became the Automatic Direction Finders (ADF) in use at the present time.

Since the 1930's, different frequency bands have been assigned to ATC, airline radio station operation (Aeronautical Radio, Inc., or ARINC), and commercial broadcast stations. This tradition has been kept although the specific frequency allocations have been shifted.

World War II (WWII) brought the rapid expansion of the aviation industry to meet defense needs. More modern (jet) and larger aircraft were developed with four and six engine reliability for long distance operation and increased load capacity. The need for round-the-clock operations caused increased emphasis on low-visibility all-weather approach systems. The development of radar to detect enemy aircraft led to the development not only of the Ground Approach System, but also to the surveillance radars of today's ATC environment.

II. Evolutionary Changes in Communications and ATC

This historical review of the changing role of communications in aviation indicates that the developments of both aviation technology and communications technology, and their interactions in the early days of aviation through the 1940's, were spurred substantially by the two World Wars. This suggests a close relationship between military and civil aviation and aviation communication technologies, both in the past and in the future. In fact, many technology forecasts have been based on a heuristic approach, in which the military technology was found from historical data, and assumed to be a precursor of its civilian counterpart by a certain number of years. The projection of civilian aircraft speeds has been used as a classic example of this approach [5]. However, with socioeconomic structural changes, the same heuristic

approach may be inapplicable. The slow progress of civilian aircraft speed beyond the supersonic provides such an example. For the present study, it is useful to compare the progress of ATC and that of communication technology.

The orderly change in the U.S. Air Traffic Control System is often described in terms of ATC generations. The time periods for each generation are not distinct since the development was an evolutionary process. Figure 2.1 provides a 1975 view of the generation pattern with approximate time frames and significant characteristics [17]. The same figure also contains a time chart with markers, showing the approximate dates of ATC generation shifts, which appear to take about 20 years per generation. A description of the generations follows [17].

"Initial steps to formalize an ATC system were taken in 1935. Initially, there were few aids or tools, limited control was provided, no surveillance and only limited radio communications existed, primitive flight strips were manually prepared, and only limited point-to-point communication circuits were available."

"The second generation ATC system evolved following World War II and can be characterized by the widespread introduction of the Air Traffic Control Radar Beacon System (ATCRBS), and limited printing of flight strips."

ATC GENERATIONS

GENERATION	TIME PERIOD	KEY FEATURES
FIRST	1936-1950	– PROCEDURAL CONTROL – FLIGHT STRIPS – LIMITED CONTROL – MOSTLY BY A/G RADIO – P/P TLTP CIRCUITS
SECOND	1950-1970	– RADAR CONTROL, INTRODUCTION OF ATCRBS – LIMITED FLIGHT STRIP PRINTING
THIRD	1970-1975+	– NAS ENROUTE & ARTS AUTOMATION – INCREASED USE OF ATCRBS – CENTRALIZED FLOW CONTROL
UPGRADED THIRD	1975-1995	– UPGRADED ATC AUTOMATION – DABS, ASA, RNAV, MLS ETC.
FOURTH	1995- ?	– NEW SYSTEM ORGANIZATION – MORE AUTOMATION – NEW SURVEILLANCE, COMMUNICATIONS AND NAVIGATION SYSTEMS

DABS – DISCRETE ADDRESS BEACON SYSTEM
ASA – AIRCRAFT SEPARATION ASSURANCE
RNAV – AREA NAVIGATION

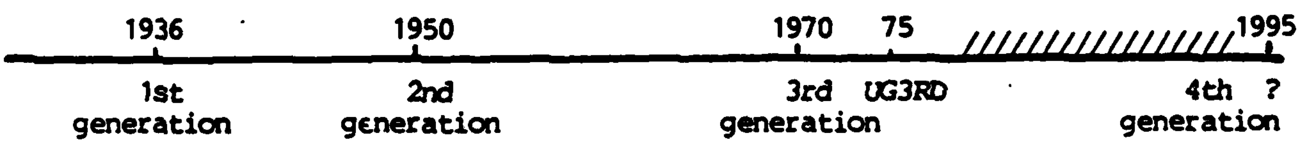


Figure 2.1 - Air Traffic Control Systems Evolution

"The third generation system can perhaps best be described as the system that is in operation today (1975). Basic automation has been added to the major terminal systems and all en route centers within the conterminous states, greater use has been made of the ATCRBS, and a centralized flow control system has been introduced."

"The upgraded third generation system -- the system that is the next generation to come -- has been initially defined but continues to evolve to some degree."

Thus, the ATC system has evolved from control based on air-derived information to control based on ground-derived information, and from raw radar data to the present radar plus beacon return data. Automation in the computer processing and display of data to the air traffic controller has been implemented and will increase as the Upgraded Third (UG3RD) Generation continues[56]. The third generation termination date is unknown and will depend on when a new and distinct type of control (e.g., a global positioning system based on satellites) emerges to define the fourth generation.

The communications industry is largely independent of aviation and its use of communications. Only a small fraction of the ground-based communication networks and of the electromagnetic spectrum are used for aviation purposes. With the advent of the

information society, the progress of communication technology seems to be accelerating. Figure 2.2 shows the increase of the capacity of major telecommunications channels on a logarithmic scale over time, with markers indicating the sequence of technical inventions in communications[70]. As shown, the capacity is projected to increase faster than the historical rate of a quadrupling approximately every decade. Moreover, the capacity of major telecommunications highways is but one of the many possible indicators of the progress of communications technology. For example, it does not capture the significance of the mutually reinforcing, interaction between computers and communications - a combination which can provide a new technological framework for ATC, hasten the advent of the fourth generation ATC, and provide an unlimited number of other opportunities to our information society. On the other hand, Figure 2.2 does not give any clue to the potential retardation of the progress of communications technology due to our legal, political, economic and social structure, which changes much more slowly than computer and communications technologies.

The point which we wish to make here is that structural changes are important in long-range technological forecasts. While the advances of military systems will continue to support the improvement of ATC and its communications system, the developments in electronics, computers, and the communications industry

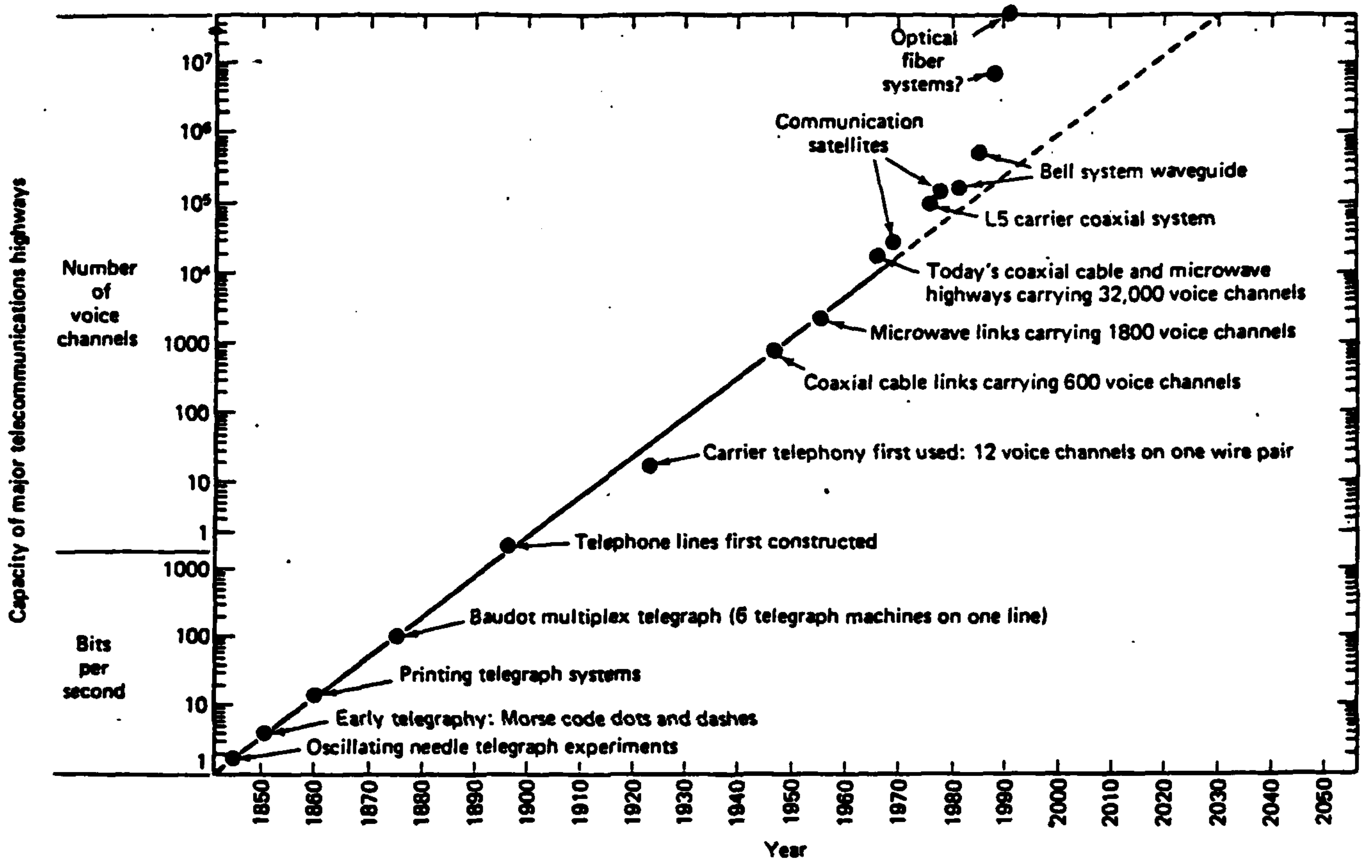


Figure 2.2 - Evolution of Communications Technology

per se are likely to assume an increasing and possible dominant role as sources of new technology for aviation communications. Therefore, in this study, substantial attention will be given to forecasts of electronics and communications technologies, with due consideration of the socioeconomic conditions which may accelerate or retard their future developments.

III. The Current Role of Communications in ATC

The control of air traffic is somewhat similar to control of surface traffic. Traffic control systems all have the same basic objective, that of passenger safety, accomplished by preventing collisions of vehicles with other objects. Further, ATC should provide for expeditious flow of air traffic, and help meet the "S3E" objectives of the NAS. Two modes of flight operation are utilized to avoid collisions: Visual Flight Rules (VFR), and Instrument Flight Rules (IFR).

To provide control of air traffic, the ATC system is divided into two segments: Terminal Control and En Route Control. The ATC Systems Command Center (ATCSCC) provides overall system direction, flow control, and altitude reservation functions [86]. Furthermore, support information functions are provided by the National Flight Data Center and by Flight Service Stations (FSS). In the following, the role of communications in the two ATC segments and in the support information functions will be discussed separately.

A. Terminal Control

The traffic density is high in the terminal area surrounding airports. The coordination function of ATC and the surveillance support function must be closely integrated. Thus, there are many communication circuits for terminal area control: the real-time air-ground links between controller and pilot, the ground-ground interphone and intercom (IP/IC)* voice coordination circuits between controllers, teletype data circuits, radar surveillance links, and computer-computer data links for the Automated Radar Terminal Systems (ARTS). Note that low traffic density terminals do not have all of these circuits.

The major elements of the terminal ATC system are the Tower and Approach Control; the latter is often omitted in low traffic density areas. As of June 1978, there were 496 towers in the ATC system, of which only 222 had approach control. The Air Traffic Control Tower (ATCT) is responsible for the initiation and termination of ATC. Nominally, three controllers are involved.

In the departure phase, communications start with the ATC clearance delivery sequence. The pilot must acknowledge the clearance by a readback. After clearance delivery, taxi instructions are received from the ground controller, who controls the flight until

*Intercom is voice communication between operational positions in a single facility; interphone is the same between separate facilities.

"hand over" to the local controller. The latter clears the flight for takeoff and provides control during the takeoff phase. The flight is then handed over to a departure controller until the aircraft is outside the terminal ATC area. The reverse procedure occurs for arriving traffic.

Table 2-1 shows typical tower positions and connectivity categories or the kinds of communication linkages which are needed. Note that only the three controllers require access to radio communication with the pilot [23]. The variation between minimum and maximum positions depends on the traffic activity. Intercom circuits between positions in the same building and interphone circuits between positions in different buildings are required for coordination and hand-off communication among the controllers. Telephone or support connections are required at the supervisor, maintenance, and administrative positions to contact local civil authorities (e.g., fire department and rescue services).

The larger ATC terminals are likely to have Terminal Radar Approach Control (TRACON). The TRACON controllers provide air traffic control for both arrivals and departures. Arriving traffic is handed over to tower control when the aircraft is near the airport, usually in the vicinity of the final approach fix. For departures, control is maintained until the aircraft is well clear of the congested area and thus out to a distance of about 40 miles. The control of the aircraft is then passed to an en route controller.

Table 2-1

Tower Positions and Connectivity Categories

Position	No. per Facility		Connectivity Categories			
	Minimum	Maximum	Radio	Interphone	Intercom	Support
Local Control (LC)	1	4	X	X	X	-
Ground Control (GC)	1	3	X	X	X	-
Clearance Delivery (CD)	0	2	X	X	X	-
Coordinator (C)	1	1		X	X	-
Flight Data (FD)	1	2		X	X	-
Supervisor (S)	1	1		X	X	X
Maintenance (MC)	1	1		X	X	X
Administrative (AD)	1	1			X	X

TOTAL: 7 15

Each TRACON controller uses radio to direct flights and is supplied surveillance information by radar displays and airborne radar beacon returns. The Automated Radar Terminal System (ARTS) has been introduced to aid the controller with automatic tracking.

Table 2-2 shows typical TRACON positions and connectivity categories [23]. Again, all controllers require radio communications with the pilots, and all positons except the administrative require interphone access.

B. En Route Control

The en route ATC system contains 25 Air Route Traffic Control Centers (ARTCC) spread throughout the airspace under U.S. jurisdictions -- 20 inside and 5 outside the conterminous U.S. Each center's area of responsibility is quite large and thus is broken up into sectors for control purposes. Each sector has well defined boundaries both horizontally and vertically. The "average" center has 35 sectors, is connected to 7 long range radars for surveillance data, receives inputs from 4 other ARTCCs and 3 ARTS. Additional support is provided by 15 Flight Data Entry and Printout (FDEP) terminals. Four telegraph circuits connect the average center with Flight Service Stations, military operations facilities, and to the airlines.

Table 2-2

TRACON Positions
and Connectivity Categories

Position	No. per Facility		Connectivity Categories			
	Minimum	Maximum	Radio	Interphone	Intercom	Support
Radar Approach & Departure (R)	2	16	X	X	X	-
Hand-Off (H)	1	7	X	X	X	-
Coordinator (C)	1	2		X	X	
Flight Data (FD)	1	4		X	X	
Supervisor (S)	1	1		X	X	X
Maintenance (MC)	1	1		X	X	X
Administrative (AD)	1	3			X	X

TOTAL:	8	34

Each ARTCC maintains control on all IFR flights in the area of its responsibility. The NAS En route Stage A computerized system has been added to automatically process flight plans and provide automatic tracking information to the controller on a cathode-ray-tube display. As an aircraft traverses the en route airspace structure, control is passed from one sector controller to another until the final hand-off to another ARTCC or to a terminal controller. Radio is used to pass control information between the aircrew and the ground controller.

Because of the large number of aircraft controlled in each area, the total number of positions in an ARTCC is in general much larger than those at the ATCT or TRACON. As shown in Table 2-3, the number of positions varies from 70 to 230. Radio access is again limited to the positions directly performing air traffic control.

C. Air Traffic Services and Support

The primary elements in this portion of NAS are flight services and weather services. Prior to a flight, the pilot starts his initial flight preparation by obtaining current NAS status information on airport and NAVAID (air navigation facility) status. Also, weather information for the intended route of flight is obtained. Once the IFR flight plan is prepared, it is entered into the ATC system through a Flight Service

Table 2-3

ARTCC Positions
and Connectivity Categories

Position	No. per Facility		Connectivity Categories			
	Minimum	Maximum	Radio	Interphone	Intercom	Support
Assistant (A)	6	45		X	X	-
Coordinator (C)	8	15		X	X	-
Handoff (H)	0	30	X	X	X	-
Manual (D)	25	60	X	X	X	-
Radar (R)	25	60	X	X	X	-
Supervisory (S)	4	15		X	X	-
Maintenance/ Administrative	2	5		X	X	

TOTAL: 70 230

Station (FSS). This procedure is optional for VFR flights.

During the en route portion of a flight, the pilot is provided weather information on selected NAVAID frequencies, by the En route Flight Advisory Service at selected FSSs. The pilot is encouraged to submit pilot reports on significant weather conditions. Flight plans may be closed out through a FSS either by radio or by telephone after landing.

There are 319 FSSs, 6 Combined Station/Tower, and 7 International FSSs. The flight plans are entered into the ATC system by FSS personnel using the Service B teletype system. Since the FSSs are widely distributed, many have the function of monitoring the operation of NAVAIDs. This is accomplished through remote tone control equipment that indicates trouble status in an on or off mode. Coupled with this function, FSSs also originate Notices to Airmen (NOTAMS) concerning the operational status of airports, navigation aids, communications outlets, and facilities [24].

Additionally, FSSs are one of the main focal points for aviation weather data acquisition and dissemination. Observation data is distributed to processors and directly to users on a national telecommunications system. Processed data, such as National Oceanic and Atmospheric Administration (NOAA) forecasts, are relayed to aeronautical users via the same national telecommunications system [24].

Given their multiple functions, it is therefore not surprising that FSS communication loads are heavy. In 1977, FSS Specialists provided nearly 17 million briefings, in person, by telephone, or by radio. The FSS air-ground communications with aircraft has several links. There is an air-ground radio transmitter/receiver link through a Remote Communications Outlet or Single Frequency Outlet, and a receive-only Limited Remote Communications Outlet (at a VOR/VORTAC site). The nondirectional Beacon provides voice transmission capability along with the beacon for ATC. All of these facilities provide means for the FSS to communicate with aircraft and provide the support and weather services.

D. Impact of Automation

FAA studies show that as much as 80 percent of a controller's time may be spent on the microphone [83]. This voice link is maintained through (1) the interphone circuit from one center to another for inter-center coordination, (2) the intercom circuit within the same center for intra-center coordination, and (3) the radio outlet connection with remote radio sites for communication with pilots. In the future, many of these functions performed by voice communications will be automated in order to improve controllers' productivity, increase the airspace capacity, and to keep the ATC costs down. The extent and the speed of ATC

automation will depend on a number of factors, such as technical development, man-machine interaction, safety considerations, and institutional adaptability to change. Nevertheless, it is clear that, with the trend toward increased automation, one form of communications, voice, is yielding to another form, data.

IV. Categorization of Aviation Communications

It is clear from the role of communications in aviation that the operational functions, technical means, and organization arrangements for aviation communications are varied and multifarious. One can, therefore, derive any number of taxonomies for categorizing aviation communications. For the present study, three criteria for an appropriate taxonomy were considered:

- o Ease of data collection - This would favor a traditional taxonomy as it may be difficult to reassemble past records to fit new categories.
- o Technical system design - This would favor a separation of air-ground communications from ground-based communications since the former are much more constrained by frequency allocation than the latter.
- o Regulatory considerations - This would favor a separation of the portion of aviation communication that utilizes networks owned by the regulated communications industry (especially the common carriers) from the portion that does not.

Application of the above criteria has led to the categorization of aviation communications as follows:

- o Radio Communications System (RCS),
- o Voice Communications System (VCS), and
- o Data Communications System (DCS).

This categorization is traditional, and has been used explicitly by Aeronautical Radio, Incorporated (ARINC), the Radio Technical Commission for Aeronautics (RTCA), as well as the FAA [53]. On balance, this taxonomy satisfies all the above three criteria.

It will be difficult to draw sharp demarcation lines between the three categories. For the purpose of this study, RCS includes all aviation communication systems which include a radio link. Thus, this category consists of all the air-ground communications, both voice and data. A major component will be the radio systems which provide voice communications between controllers and pilots, as detailed in Tables 2-1, 2-2, and 2-3. Such communications are needed when the pilots are in their aircraft, whether they are in the air or on the ground. However, it includes other important non-ATC communications, such as between an airline pilot and his company office.

RCS will include aviation communications systems which transmit data over a radio link. A significant increase in its use will come with the implementation of the Discrete Address Beacon System (DABS), which will permit automatic communications

between the ground-based ATC with the transponders on the aircrafts. All communication systems associated with Collision Avoidance Systems (CAS), whether they are airborne (ACAS) or beacon-based (BCAS), are also within this RCS category. Note that ACAS involves only air-to-air communications.

To facilitate technical design considerations (the second criterion), aviation communications systems under RCS will be treated as self-sufficient systems. Thus, for example, the ground circuits and amplifiers feeding the radio links, the remote radio communication control equipment, the antenna towers, as well as all the airborne communications equipment, are included. From the standpoint of regulation, all the radio links must, of course, operate within the allocated frequencies. FAA will thus be the principal regulatory agency influencing technology adoption, transfer, and diffusion in the RCS category.

VCS and DCS include all the ground-based aviation communication systems without a radio link. They serve not only the air traffic control functions, but practically all other FAA functions: administrative, maintenance, research, and engineering. For ATC functions, VCS consists mainly of the intercom/interphone systems referred to in Tables 2-1, 2-2, and 2-3, while DCS consists mainly of the communications of records (e.g., flight plans over teletypes)

and computer data (such as between ARTCCs). The traditional distinction between VCS and DCS is partly historical and partly technical. In general, voice communications, typically over telephone, are basically analog and continuous, whereas data communications, typically between computers and their associated terminals, are basically digital and bursty. Table 2-4 shows a comparison between telephone and computer traffic characteristics, which affect the design of their corresponding communications systems [71]. However, the general future trend is to convert voice signals to digital form and transmit them along with digital data, especially for long-distance communications. The distinction between VCS and DCS will therefore tend to decrease in the future.

In either the VCS or DCS case, aviation communication users will have the option of owning, leasing, or subscribing to ground-based lines and networks. The circuits are owned by communications companies, including the common carriers, which have very little or nothing to do with aviation. The state-of-the-art technology used in such systems is therefore much more dependent on the non-FAA regulations: the 1934 Communications Act, the Federal Communications Commission (FCC), the former Office of Telecommunications Policy (OTP), and the newly established National Telecommunications and Information Administration (NTIA) under the U.S. Department of Commerce.

TABLE 2-4

Telephone and Computer Traffic Characteristics

Telephone Users	*Computers and Terminals*
• Require a fixed capacity channel.	• Require a very wide spread of channel capacities ranging from a few bits per second to (ideally) millions of bits per second.
• Always carry out a two-way conversation.	• One-way or two-way transmission.
• Tolerant to noise on the channel.	• Data must be delivered without errors.
• Transmit or listen continuously until the call is disconnected.	• In a man-computer dialogue, transmission is in bursts.
• Require immediate delivery of the signal.	• In non-real-time data transmission the data can be delivered later, when convenient.
• The transmission rate is constant.	• In a man-computer dialogue the mean number of bits per second is usually low, but the peak requirement is often high. The peak to average ratio is often as high as 1000.
• The time to set up the connection can range from a few seconds to one minute.	• Sometimes it is desirable that the connection should be set up in a second or less.
• Switching is carried out only at the start of a conversation.	• Efficiency can be improved if the messages which constitute a dialog are individually switched with a very low switching time.
• Telephone dialing is manual.	• Setting up a connection between machines is often automatic.
• Telephone callers employ simple compatible instruments.	• Incompatible machines may intercommunicate giving a need for code or signal conversion.

This study is intended to include all the three categories of aviation communication systems for technology forecast and assessment. However, since the ultimate objective is to help FAA policy development, major emphasis will be placed on RCS, with some attention given to VCS and DCS to the extent that they may have FAA policy implications. The next chapter will describe the more important aviation communication systems in each of these categories and their respective roles in air traffic control and other functions of the NAS.

CHAPTER THREE

DESCRIPTION OF NAS COMMUNICATION SYSTEMS

This chapter, which contains the main body of technical information for this report, consists of five sections. Section I, NAS Communication Systems, will present an overview of the National Airspace System (NAS), and its communication facilities. As we have previously classified NAS Communication Systems into three categories, Sections II, III and IV will present detailed descriptions of each of these categories in turn.

Sections II, III and IV will describe the Radio Communications System (RCS), the Voice Communications System (VCS), and the Data Communications System (DCS) respectively. Section V presents an overview of the projected 1985 FAA communications system.

I. NAS Communications Systems

The National Airspace System (NAS) is composed of both the U.S. airspace and the navigational aids and communications facilities necessary to carry out the basic purpose of NAS operations, viz: the safe and efficient use of the airspace. The elements of the NAS may be categorized into three categories, namely:

- o Terminal Air Control and Services,
- o En route Control and Services, and
- o Flight Services.

These major subsystems of the NAS are illustrated in figures 3.1 through 3.3 respectively.

The major facilities of Terminal Air Control and Services are:

- Air Traffic Control Towers (ATCTs), which control the movement of aircraft in the vicinity of an airport and on the ground.

- Terminal Radar Approach Control (TRACONs), which provide terminal radar separation and control services to arriving, departing and transient aircraft in the vicinity of one or more airports,

- Remote Transmitter/Receiver Facilities (RTRs), which house radio transmitters and receivers for terminal area voice communications with pilots, and

- Terminal Radar/Beacon Facilities, which supply range and azimuth information for aircraft in the terminal area.

The major facilities of En route Control and Services are:

- Air Route Traffic Control Centers (ARTCCs), which control en route air traffic flow between terminal areas,

- Remote Communications Air Ground Facilities (RCAGs), which house transmitters and receivers for voice communications between an ARTCC and pilots,

- Long Range Radar Sites (LRRs), which provide high altitude surveillance for en route control centers, and

- The Air Traffic Control Systems Command Center (ATC-SCC). which coordinates flow patterns system-wide and distributes air traffic between en route traffic control centers.

Finally, the major facilities of Flight Services are:

- Flight Service Stations (FSSs), which provide support to general aviation, such as weather briefings, filing of

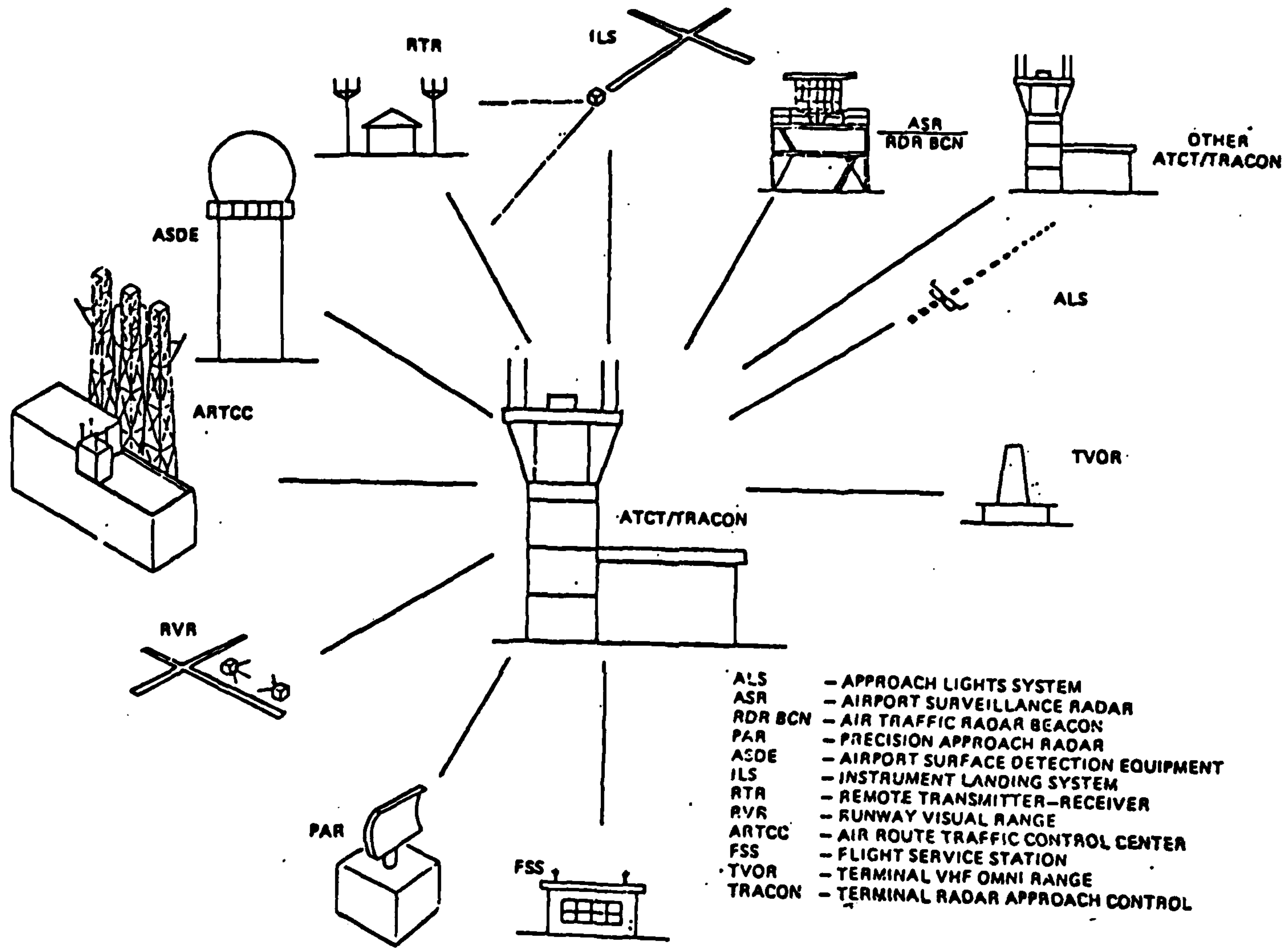


Figure 3.1 Terminal ATC System

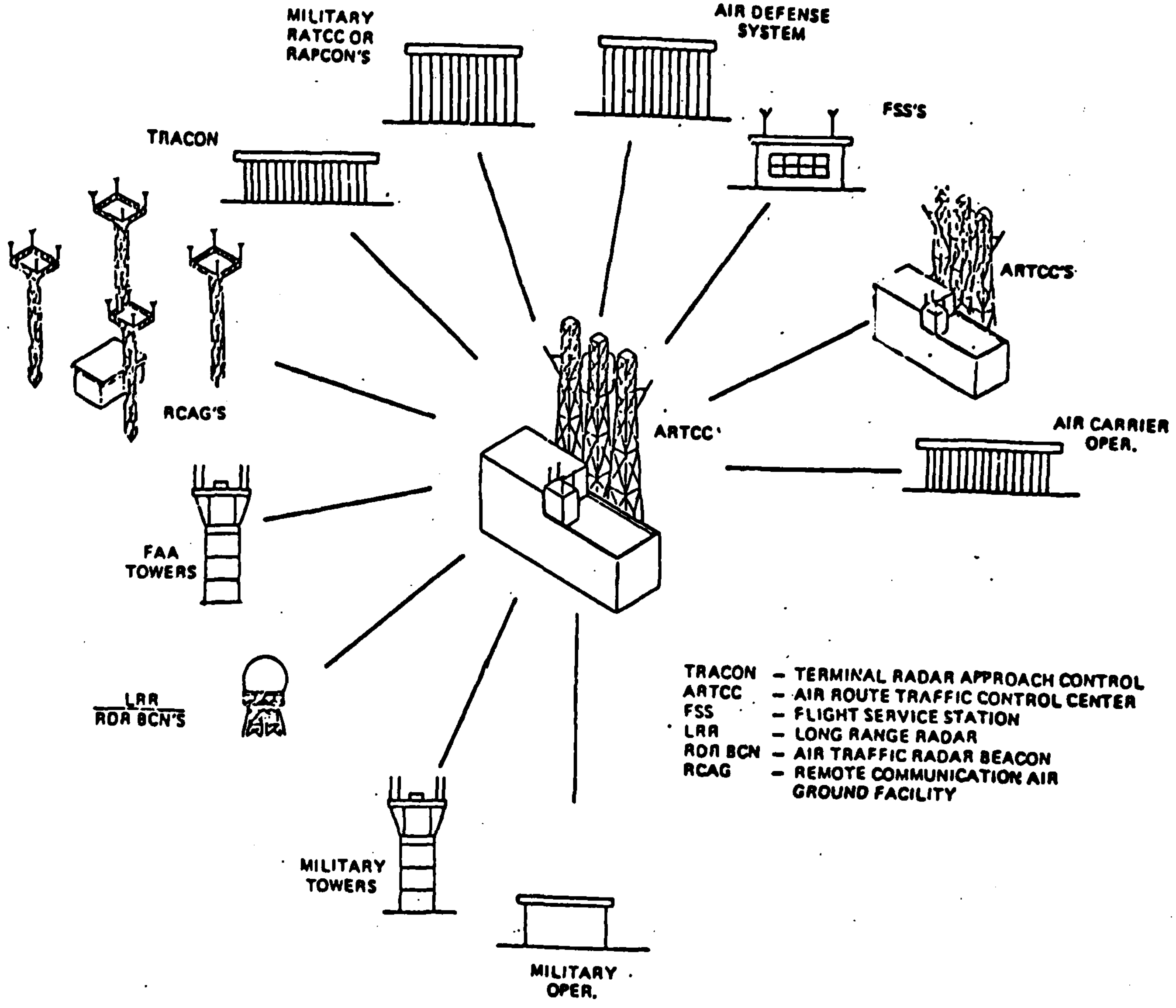
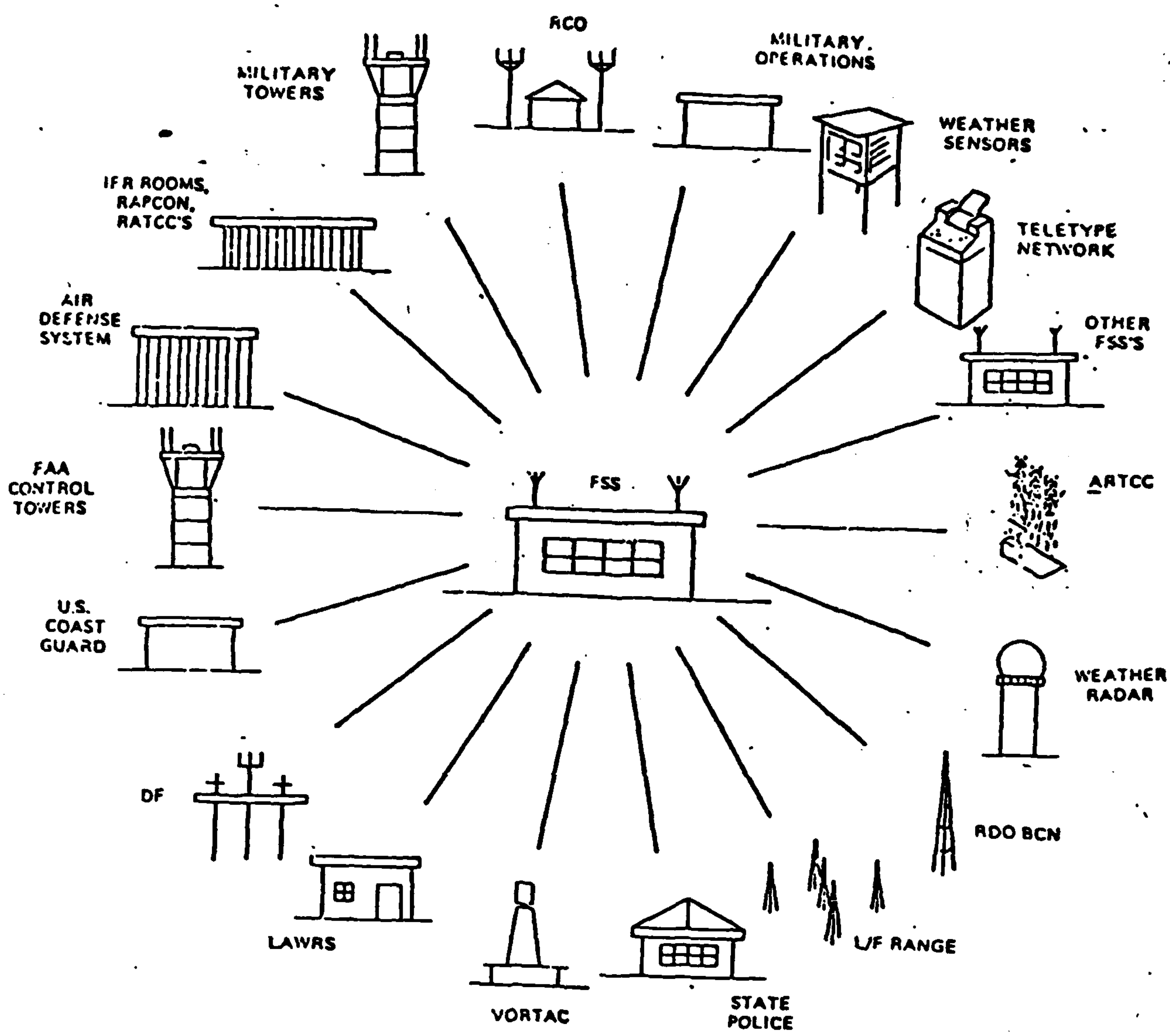


Figure 3.2 En route Traffic Control System



FSS	– FLIGHT SERVICE STATION
DF	– DIRECTION FINDER
RCO	– REMOTE COMMUNICATION OUTLET
RAPCON	– RADAR APPROACH CONTROL (AIR FORCE)
RATCC	– RADAR AIR TRAFFIC CONTROL CENTER (NAVY)
ARTCC	– AIR ROUTE TRAFFIC CONTROL CENTER
RDO BCN	– RADIO BEACON
LAWRS	– LIMITED AIRPORT WEATHER STATION

Figure 3.3 Flight Service Station

flight plans, issuance of airport advisories and Notices to Airmen (NOTAMS), as well as the processing of Pilot Reports (PIREPS),

- VHF/UHF Navigational Aids (VORTACs), which provide the combined VHF and UHF navigational aids monitored by Flight Service Stations, and

- Remote Communications Outlets (RCOs), which provide air-to-ground communications for Visual Flight Rules (VFR) aircraft.

A. NAS Communication Subsystems

Communication systems which support NAS operations consist of independent systems which fall into one of the three categories: Radio Communications Systems (RCS), Voice Communications Systems (VCS), or Data Communications Systems (DCS). The available communications services within each of these three categories (Figure 3.4) is summarized below.

The major component of the Radio Communications System is Air-Ground communications, operating in voice mode on Very High Frequencies (VHF) for civilian aircraft, and on Ultra-High Frequencies for military aircraft. This mode of communications, for the purpose of Air Traffic Control (ATC) and for flight support services, connects ATC towers, Terminal Radar Approach Control (TRACON), and the ATC Systems Command Center, with flight support services.

The Voice Communications System provides Interphone Communications (Service A) for the purpose of exchanging flight movement

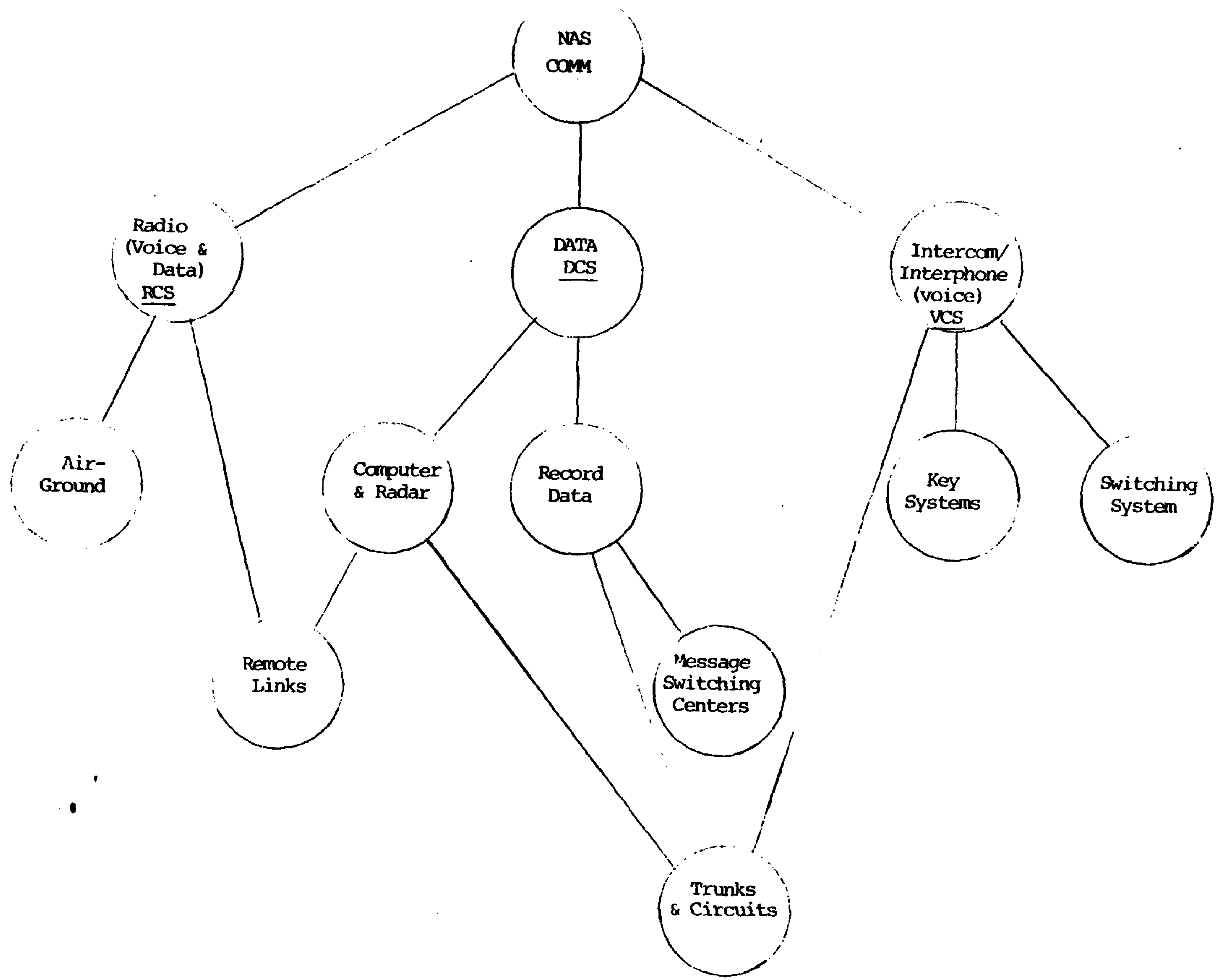


Figure 3.4 NAS Communication Systems

information in voice mode between all FAA facilities, and <u>Intercom</u> service for communication within a facility.

The Data Communications system contains four major components: Data Communications (Service B), Aeronautical Fixed Telecommunication Network (AFTN), Modernized Weather Teletypewriter Communications Service (MWTCS), and Remote Link Services Communication. These DCS components are described below.

<u>Data Communications</u> (Service B), provides a mixture of teletype and medium speed data circuits operating in the geographic area of two or three Air Traffic Control Centers (ARTCCs). Service B circuits collect and distribute flight plan information.

<u>AFTN Communications</u> (the Aeronautical Fixed Telecommunications Network), is a worldwide network of land lines, satellites, submarine cables, and high-frequency radios connected by switching centers at major world aeronautical locations. The International Aeronautical Communications Switching Center (IACSC) located in Kansas City, controls the operations of the AFTN, transferring communications traffic of flight plans, flight movements, and meteorological information.

<u>Modernized Weather Teletypewriter Communications Services</u> (MWTCS), is a centralized message switching center for collection and dissemination of weather information. Three teletype weather

networks are consolidated into the MWTCS: Service A (aviation weather and forecast), Service C (synoptic meteorological information), and Service O (international weather information).

Remote Link Services Communication connect field facilities of the NAS with major terminal and en route locations within the United States. These facilities include Remote Microwave Links (RMLs) for transmitting surveillance data collected at Long-Range Radar Sites (LRRs) to en route centers, radar links to IFR (Instrument Flight Rules) rooms for display of aircraft tracks, and other links between ATC navigational aids to terminal areas and Flight Service Stations.

Table 3-1 summarizes the total circuit miles which are used in each of these types of facilities. The circuit miles listed include both government owned and leased circuits. Table 3-2 details the number and type of FAA facilities located throughout the country. Figure 3.5 diagrams the communications elements which support the NAS.

TABLE 3-1

SUMMARY OF PRESENT LEASED COMMUNICATIONS SYSTEMS AND GOVERNMENT OWNED CIRCUITS

SYSTEM/NETWORK	TYPE OF COMMUNICATIONS	CIRCUIT MILES
System B	Teletypewriter, low and medium speed	150,000
Service F	Voice	560,000
WMSC*	Teletypewriter, low and medium speed	330,000
Air/Ground	Voice and Keying	700,000
Radar Microwave Links (RML) Leased and govt. owned	Video, data and voice	16,000
AFTN	Teletypewriter	130,000
FDEP**	Low speed	20,000
ARTS/ARTCC	Medium speed	9,000
	TOTAL	1,915,000

* Weather Message Switching Center

** Flight Data Entry and Printout

TABLE 3-2

SUMMARY OF FAA FACILITIES

The number of major installations that contain communications equipment are listed below (based in part on ATC Fact Book, dated June 30, 1978):

FAA FACILITY	NUMBER OF FACILITIES (1978)
ARTCC Domestic - (Foreign)	20 (5)
TRACONs	233
TOWERS	496
FSS Stations	319
RCAG Sites	470
LLR Sites	107
VOR/VORTAC Sites	1,021
RCO Sites	54
LRCO Sites	627
DF Services	206
RTR Sites	250 Estimated
NATCOM (Kansas City, Mo.)	1
SCC (Washington, D. C.)	1
NFDC (Washington, D. C.)	1
NAFEC (Atlantic City, N.J.)	1
OKC	1
Regional Offices	12 (includes Alaska and Europe)

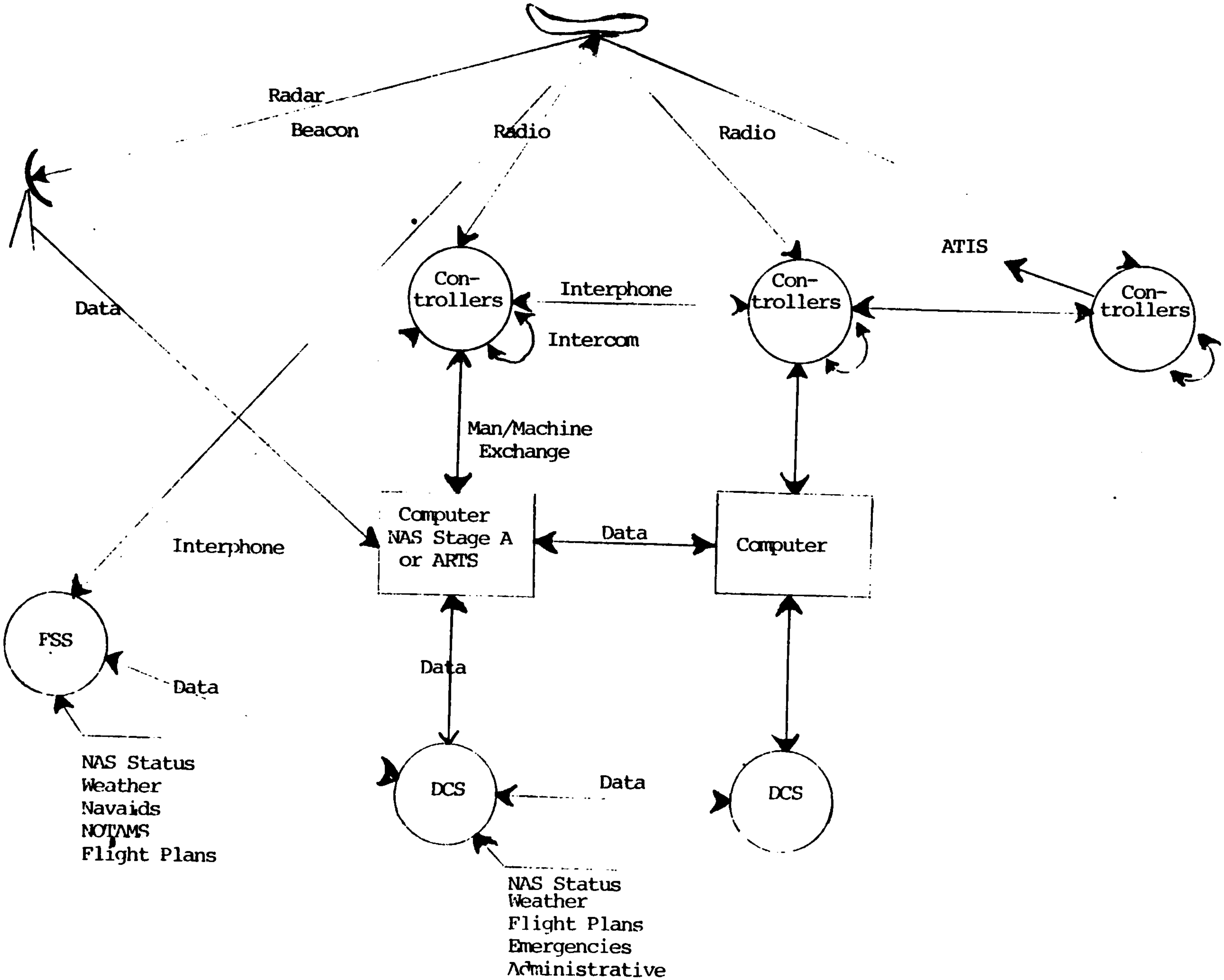


Figure 3.5 Generalized NAS Communications

B. Evolution of NAS Communications

In its embryonic stages, air traffic control developed as a manual system in which the controller recorded information on flight progress strips. However, the increasing volume of aircraft traffic caused the air traffic controllers to become overburdened with these duties, and distracted them from their primary responsibility of maintaining aircraft separation.

The incorporation of radar into air traffic control allowed more airplanes to be handled safely. However, this technical advance did not completely eliminate manual operations from the controller's tasks. Controllers were still required to track aircraft on radar displays by manually positioning plastic chips called "shrimp boats". Recognizing the need for increased automation, an NAS design was developed by an FAA system design team, which incorporated the concepts of the "Project Beacon Report". The designed NAS was intended to be an automated air traffic control system that could insure safe and efficient utilization of the airspace.

The first step in this upgrading of air traffic control was the "NAS En route Stage A" program, which was meant to increase the air traffic handling capabilities while improving safety. This goal was to be realized by attaining the following objectives:

- Automating transfer and processing of flight plan information,

- Automating radar identification of aircraft in the system,

- Automating display of altitude or flight level information and aircraft position, and

- Increased computer processing capabilities to serve as the basis for future improvements.

As planned in 1960, the NAS En route Stage A would represent a semi-automatic system with the following automated features:

- Entry and processing of flight plan information,

- Flight progress strip printing at the appropriate sector position,

- Provision for entering and receiving new and revised flight data at all operating stations,

- Display of radar data to assist in aircraft identification,

- Automatic tracking of each aircraft,

- Coordination between sectors for display at computer generated data,

- Facility coordination through the use of computer transmitted data, and

- Computer generated geographic and weather maps.

The NAS En route Stage A was aimed at decreasing the amount of manual effort required to collect, process and display flight data. Controllers would have more time available for decision making and thus their decisions would be based upon more accurate data.

Implementation of NAS En route Stage A was planned to take place in stages, to correspond with the increased traffic flow handled by air traffic control facilities. Using the current air traffic control system as a base, increasing capabilities would be provided as needed by a particular facility. Eventually, all facilities would receive "NAS ATC Equipment" when warranted by traffic conditions.

In the first stages of implementation, five on-line computer systems were installed in the Air Traffic Control Centers of New York, Boston, Cleveland, Indianapolis and Washington. These computers relieved controllers and assistant controllers of some of their computational and clerical responsibilities and were programmed to:

- o Receive and store flight plans,
- o Compute estimated times over fixes in the flight route and estimated times of arrival at destinations,
- o Print flight progress strips, and
- o Transmit flight plan information to other centers.

Subsequent to the installation of these five computer facilities, the FAA undertook two service improvement programs, the Advanced Radar Traffic Control System project (ARTS), and the Stored Program Alpha-Numeric Project (SPAN). The ARTS project, based on primary and secondary radar systems, provided an alpha-numeric radar tracking capability for air traffic control.

terminals. The SPAN project applied these same capabilities to the en route control environment. The capabilities developed during these projects were implemented in the Jacksonville ARTCC installation.

In the next stage of NAS En route State A implementation, which took place from 1968 to 1970, Flight Data Processing Systems (FDP) and Alpha-numeric Display Systems (ADS) were installed at the following ARTCC's: Chicago, Washington, Los Angeles, Fort Worth, Kansas City, Indianapolis, Oakland and Denver.

The Flight Data Processing System included the following capabilities:

- o Accepting, storing and disseminating flight plan information,
- o Calculating and updating flight data, and
- o Transferring data within facility and to adjacent facilities.

In conjunction with the FDP system, the Alpha-numeric Display System (ADS) provided:

- o Automatic aircraft tracking,
- o Visual flight information display, and
- o Automatic radar hand-off capabilities.

The final phases of implementation of "NAS En route Stage A" include installation of FDP and ADS at all of the remaining

ARTCC's without implementation of the intermediate steps. All large hub terminal areas would receive similar NAS en route facilities, while other areas would receive equipment comparable to the ARTS.

In the Sections to follow, the three types of the NAS communication systems will be reviewed in turn. For each system the data channels and the type of data transmitted are identified, and the systems currently in place are described. In addition, the requirements for future systems and the capabilities which they are likely to contain will be described.

II. The Radio Communications System (Voice)

The Radio Communications System (RCS) provides for voice mode communications between pilots and ground based air traffic control personnel. As such, it provides the primary ATC links, and has become nearly synonymous with air-ground communications.

The NAS air traffic control operation divides the 48 conterminous states into 20 Air Traffic Control Center (ARTCC) areas with an additional five ARTCC areas located in Alaska, the Pacific, Atlantic, and Caribbean Oceans. Within this controlled air space, the FAA is responsible for providing air-ground ATC communication, navigation aids, and support services to aircraft flight operations. ARTCC facilities provide the en route air traffic control coverage, while terminal air traffic control is provided by TRACON and air traffic control towers, and support services provided by the Field Service Stations (FSS).

The ARTCC en route operation provides ATC by individual controllers assigned to specific air space sectors. These controllers communicate with the air crew using a line of sight radio link from a remote facility called an RCAG (Remote Center Air-Ground Communications Facility).

Terminal ATC operations, both tower and approach control provide air-ground radio communications using a combination of local and remote sites called RTRs (Remote Transmitter/Receiver Facilities).

FSS operations provide air-ground support communication via remote sites called RCOs (Remote Communications Outlets), LRCOs (Limited Remote Communications Outlets), and SFOs (Single Frequency Outlets). RTRs may also be used with an FSS, and RCOs may be used for terminal operations.

These remote and local radio communications sites are operated by the controller from a console using radio control equipment on each end of a link between the operating position and radio site. The Radio Communications Control System (RCCS) not only controls the radio equipment at a site, but also provides the audio path between the controller and the transmitters/receivers.

Frequency allocations for VHF air-ground communications are 118.0 MHz to 136 MHz. The current 50 kHz channel spacing is being reduced to a 25 kHz spacing for high altitude en route operations.

A. Air-Ground Links

There are 470 RCAGs serving the 25 ARTCCs. Each RCAG facility has a standard shelter configuration, available in three sizes to accommodate the required equipment (10, 16, or 20 radio racks). Four antenna towers are associated with each shelter and each tower provides mounts for antennas. Thus, 16 separate antennas are available for each facility. Tower separation is 80 feet,

while antennas are mounted a minimum of eight feet apart on the tower. Each radio transmitter and receiver and an RCAG is backed up by a spare transmitter and receiver. Currently, the transmitters and receivers are being converted to solid state AN/GRT-21, -22 and AN/GRR-23,-24 equipment. Conversion to solid state equipment is approximately 90% complete, and should be completed by 1985.

Additionally, Back-Up Emergency Communication (BUEC), is provided for ARTCC air-ground communications. These facilities are usually located at a Long Range Radar (LRR) site. The tunable transceivers (combination transmitters and receivers) used are connnected to the ARTCC site by Radar Microwave Links (RML), voice channels, or Telephone Company (TELCO) circuits.

There were 425 terminal communications facilities employing 3,835 radio frequencies as of 1975. These facilities, serving both TRACONs and ATCTs, employed transmitters and receivers of the vacuum tube variety. Redundant transmitters and receivers for terminal areas often take the form of stand-by equipment at the same site, equipment located at different sites, or equipment located within the ACTC or TRACON. Tertiary back-up is provided for critical frequencies.

Some of the communications workload at an ATCT has been reduced in facilities where an Automatic Terminal Information Service (ATIS) has been installed. Airport information such as runway

conditions, barometric pressure, wind direction and speed, ceiling and visibility, is recorded and broadcast over a NAVAID or other frequency. Updates are made periodically to keep this information current, and the system relieves the controller from repeating the information over and over.

FSS air-ground communications support sites number in excess of 1,000. This is composed of 319 Flight Service Stations, 54 Remote Communications Outlets (RCOs), 627 Limited Remote Communications Outlets (LRCOs), and Single Frequency Outlets (SFOs). Since the FSS provides non-Air Traffic Control functions, and the available air-ground radio channels are limited, the FSS frequencies are fewer than those for ATC operations.

FSS shelters are of several configurations, with antennas mounted on the roof of the facility or at a nearby remote facility at the airport. Frequently, terminal communications facilities house FSS radio channels. The RCO is remotely located in a shelter similar in configuration to the FSS. The LRCO is usually located with a VOR and is comprised of receive-only equipment with a pole-mounted receive antenna. The SFO is either a single frequency facility located within another FAA facility, or is a self-contained shelter with a pole mounted antenna.

Along with these remote sites, FSSs also use the NAVAIDS (VOR, VORTAC, and NTB) for air-ground broadcasts. This system is ground

transmit only, with aircraft transmissions heard on a specified receive-only frequency by the specialist. Transcribed Weather Broadcast Service (TWEB) is also used to provide timely weather information to aircraft. Along heavily traveled routes, an En Route Flight Advisory Systems (EFAS) provides coverage from key locations. The EFAS is manned by trained weather specialists in selected FSSs.

B. <u>Radio Communications Control System (RCCS)</u>

The RCCS is a subsystem of the overall Radio Communications System (RCS). Its facilities include position equipment, control equipment, links between control sites and remote sites, and far end remote control equipment.

At a control position the normal equipment includes a microphone, head set, push-to-talk switch, and the control panels for transmitter and receiver selection. Older versions are four-channel control equipment, while new equipment is generally eight-channel. Channel capacity is expandable in four or eight channel increments to 24 channels, and can be expanded to 48 channels.

Receiving channel control equipment allows the controller to select the desired radio channel from those connected into the position by patch panel and cables. Both the receiver selector and the mixer panel provide attenuation of the radio signals for

proper isolation of the received signals. The input circuit to the control equipment connects to a patch panel, a line amplifier, and then to a remote site through telephone circuits.

Transmission control is similar to reception control. Lights are provided on the selection panel to indicate channel not-in-use, and channel in-use. Selection of a busy channel causes a busy tone or a buzzer to sound as an alarm indication. Microphone output from the position is amplified to provide proper audio-line level for input to the modulator at the transmitter site.

The control system also provides interface with the facility interphone/intercom system. Both the radio and telephone recorder input are combined in a mixer amplifier. An output is provided to the position recorder so that all position audio can be recorded.

Voice Frequencies (VF) tone control is used to provide remote switching capability and voice communications on the same circuit. The system operates in the audio frequency range sending and receiving discrete audio tones between the control and remote sites. At the remote sites, the tones activate switching equipment, key transmitters, and mute receivers. This VF tone control is used with the older four-channel equipment and is primarily located in ARTCC/RCAG facilities.

The control equipment also provides for split or paired channel operation. This allows the UHF (military) and VHF (civilian) frequencies to operate simultaneously over a single telephone circuit. In the split mode, two separate circuits are provided to operate the UHF and VHF equipment independently. Even in the paired mode, by selecting either the UHF or the VHF channel on the position selector, individual UHF or VHF channel operation is possible.

In addition to the above described FAA facilities, three other radio communication systems exist: those of the military, ARINC, and UNICOM.

C. Department of Defense

The Department of Defense operates and maintains NAVAIDs, Radar, and communications equipment, both unilaterally and with the FAA on a joint use basis. Air-ground communication facilities for voice transmission are primarily on the UHF or military frequencies. Radars maintained are for both terminal areas and the long-range radars that are used for air defense purposes. LRRs are also used for air traffic control, and are thus operated on a joint use basis with the FAA. Terminal facilities providing ATC operate with the FAA system and have similar equipment, with the exception that the predominant radio channels are UHF.

D. Aeronautical Radio, Incorporated (ARINC)

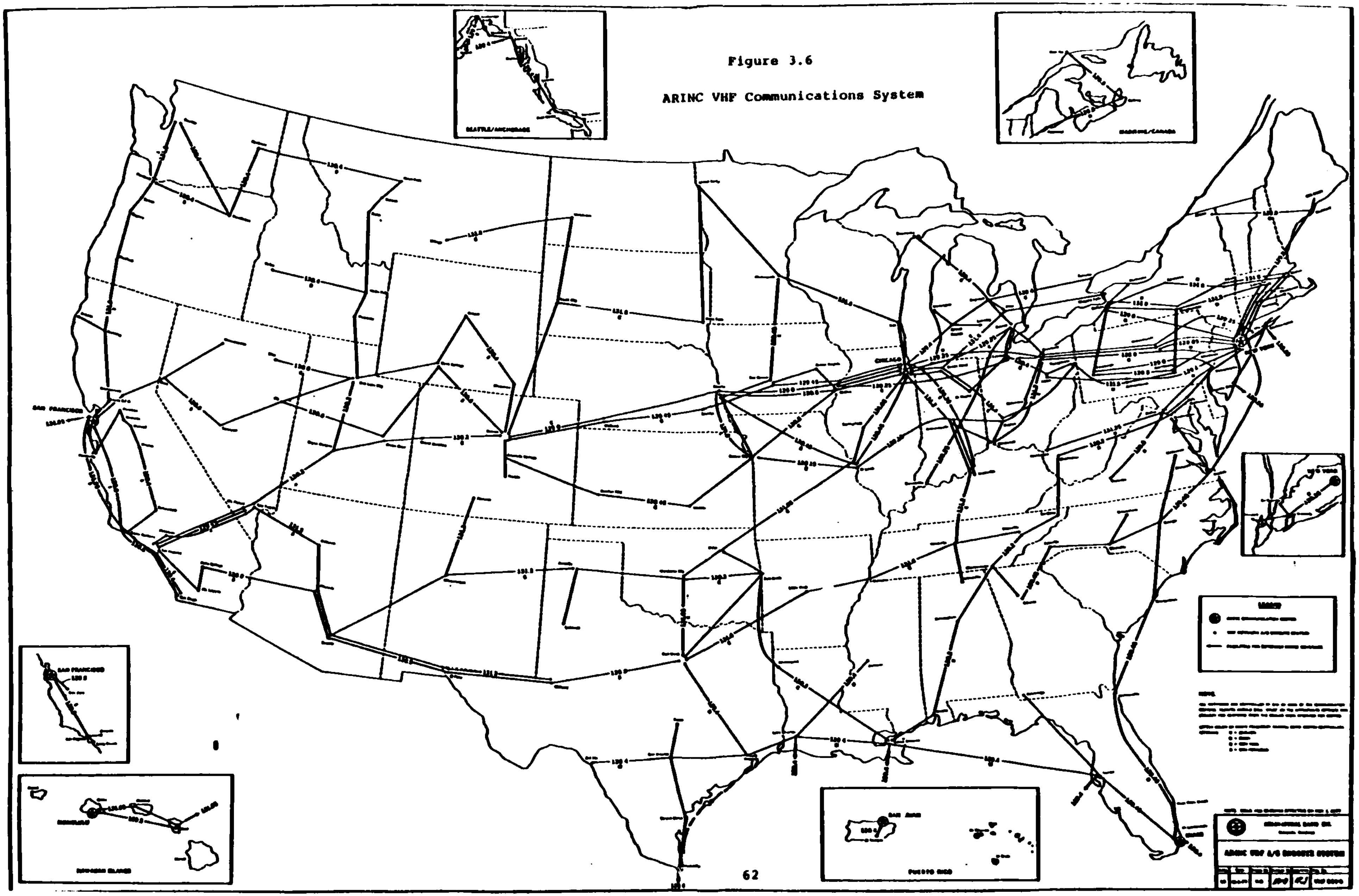
Aeronautical Radio, Incorporated (ARINC), was formed in 1929 with the airlines as principal owners and users. ARINC operates a domestic network of over 1,600 ground radio stations that provide operational control communications. This covers those communications necessary for safe and economical aircraft operations. The ARINC network of VHF air-ground en route communications is shown in Figure 3.6. This system satisfies the FAA requirement that the domestic and flag carriers provide the two-way air-ground system connecting aircraft and dispatch offices.

ARINC also operates one of the largest private message switching and processing systems, the Electronic Switching System (ESS). This system provides nationwide voice and data circuits to connect airline offices, provide weather information, and ground communications for the VHF network centers.

Outside of the conterminous U.S., ARINC operates VHF stations to provide both operational and air traffic control communications. Some of these stations have extended range features to provide VHF gateway services as far as possible over oceanic routes. ARINC also operates an international High Frequency (HF) radio system that provides the ICAO world air route area both high frequency and operational control coverages.

Figure 3.6

ARINC VHF Communications System



E. UNICOM and MULTICOM

UNICOM stations are operated by individual licensees at various airports. They provide the limited communications necessary for the safe and expeditious operation of aircraft, similar to the services provided to the airlines by ARINC. Most operate on 122.8 MHz with additional facilities on 122.85 MHz, 122.95 MHz and 123.05 MHz. These stations provide information on servicing, fuel availability, lodging and other facilities.

MULTICOM stations operate on 129.9 MHz and the assignments are phased between government and nongovernment operators. Communications are used for fire fighting, agriculture and other operations requiring aircraft.

Additional frequency allocations are made for flight test use, flight instruction use, airdrome control at non-FAA private airports, and for mobile vehicles operating on aircraft surfaces. Frequencies are also allocated for search and rescue operations.

F. Remote Maintenance Monitoring

The 470 unmanned Remote Center Air-Ground Communications Facilities (RCAGs) present a significant maintenance problem to Airway Facilities Service field organizations. The Remote Maintenance Monitoring System (RMMS) is currently under development to reduce these maintenance costs through a reduction in the

number of required visits to the remote facility.

As planned, the RMMS will provide the capability to accomplish monitoring, certification, diagnostic testing, and limited control over remote equipment from a central control site. Field visits to the remote sites will still be required for repair of equipment, alignment, and maintenance of the physical structures.

The envisioned system begins with the installation of monitor or sensor points on all remote equipment. For newer equipment, such as the solid state radios at RCAGs, only an interface will be required, as they already contain built-in test points. Older equipment will require modification to provide both the test points and the interface.

A general purpose interface bus will connect the sensor and monitoring points to a remote facility controller. There, a microcomputer will perform the switching function, and the remote site data will be transmitted to the control site. Existing circuits will be employed, either by multiplexing or by timesharing the line on a non-interference basis.

At the control site, the remote data will be extracted from the communications circuits and routed to the Central Processing Unit (CPU) of a computer. The computer will process the data, monitor and control the remote equipment, and issue status and

alarm data to both the local maintenance area and the System Maintenance Monitor and Control area.

In an experimental installation of a Remote Maintenance Monitoring at the Hutchinson, Kansas, RCAG, the reduction in the total RCAG facility workload was estimated to be 30%. While this reduction may not be equalled by all maintenance field offices, particularly those with few RCAGs to service, the potential cost savings are great. Installation of RMM in all RCAGs is expected to be completed in 1985, concurrent with the completion of the conversion to solid state equipment by all RCAGs.

III. The Voice Communications System

A. Service F

The Voice Communications System (VCS) of the FAA provides ground-to-ground voice communications via the intercom/interphone (IP/IC) system, known as Service F. Intercom is defined as voice communications between operational positions in a single facility, while interphone is voice communications between operational positions in separate facilities. This system encompasses both the telecommunications network supporting intercom and interphone, and voice switching equipment. Voice Switching equipment is provided at en route (ARTCC), terminal (ATCT and TRACON), and FSS facilities.

The Systems Command Center (SCC), Air Route Traffic Control Center (ARTCCs) and terminal areas, as well as the military, ARINC, airlines and security forces are connected via Service F as shown in Figure 3.7. While the circuits A (airline, ARINC), D (Air Defense Unit), L (Law Enforcement and Security), M (Military), and N (AUTOVON), are not part of the interphone service, they connect into the system at specified facilities. Substantial information is transferred over these channels, and they represent a significant part of the overall system traffic load.

The functions performed at ARTCCs, TRACONs, and ATCT, which utilize Service F are:

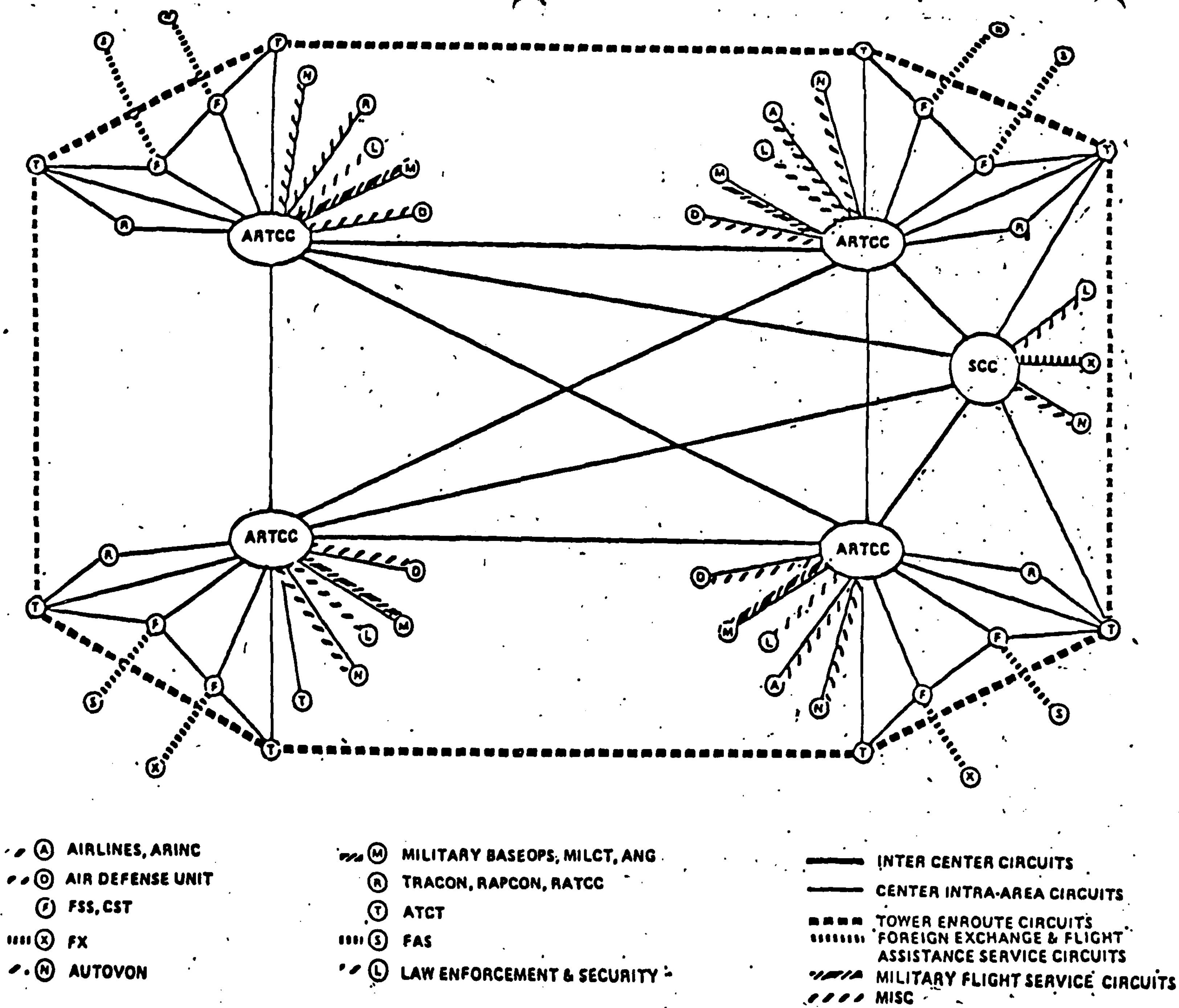


Figure 3.7

Schematic of Overall Circuitry - Service F Interphone System

- Calls between positions within a facility (the intercom function),
- Radar hand-offs from position to position within a ARTCC and between the center and positions within a TRACON or ATCT,
- Calls between FAA facilities for the coordination of the following items:
  - Flight plans,
  - Flight movements,
  - Changes in flight routes,
  - Altitude assignments,
  - Altitude reservations,
  - High Density Terminal Area (HDTA) reservations,
  - Search and Rescue (SAR) operations, and
  - Other functions requiring real time transfer of information.

Service F circuits are terminated at each facility in switching equipment which automatically connects the circuit to the called position at that facility. The calling controller, specialist, or operator, can call any other operating position within the system, with whom he may interact operationally. Smaller FAA facilities are not equipped with local switching units, and are tied to a center facility.

B. Traffic Characteristics

The nature of the traffic carried by an aviation oriented

telephone exchange is different than that handled by public exchanges. Due to the unique character of their traffic, these exchanges require a different design approach. Some of the peculiarities of such traffic are:

- o Peak load factors, holding times, and other unique traffic distribution patterns.
- o The different peaks of en route and national traffic which result in a lower coincident peak.
- o Telephone traffic within terminal and en route areas which has a higher correlation with peak air traffic than does communication traffic between loads.
- o Support communications traffic (administrative and maintenance activities) has a peak period different from the peak traffic requirements of air movements and control.
- o The blocking of exchanges must be within strict tolerances.
- o Blocking probabilities must be less than .01 (one lost call in one hundred) for switched (administrative/maintenance) support traffic, and .001 for traffic associated with air traffic control operations.
- o Priority traffic may require non-blocking service where paths are always available as a result of dedicated circuits, preemption, or redundant facilities. All communication between controllers and aircraft is "non-blocking traffic".
- o Call set up times are short and require that when a "hot line" (voice call) or air-ground voice connection is established, the first speech syllable is not lost. Dependent on the speed of switching elements, switch connections may be allowed. Dedicated non-switch paths are mandatory where the necessary switching speeds are not achieved.

Some categories of messages are given priority in handling

of the switch traffic by FAA exchanges. In descending order of priority, the messages are:

- o Emergency, which includes essential information on an aircraft accident, expected accident or potential accident. Further transmissions relative to the incident do not receive a priority rating.
- o Clearances and control instructions.
- o Movement and control messages in the following order:
  - -- Progress reports
  - -- Departure or arrival reports
  - -- Flight plans or changes to flight plans
- o Movement of Visual Flight Rules (VFR) aircraft.

The interphone network is used primarily to support flight planning activities and flight movement. Communications between the ARTCC and FSSs, BASOP (Military Base Operations Offices), airline operations, and ATCT/TRACONs, pertain in general to:

- o Filing of complete flight plans,
- o Flight progress data,
- o Flight arrival and departure information,
- o Amendments to active flight plans,
- o Critical action messages,
- o Clearances (including ATC authorized changes to the flight plans),
- o Revisions to clearances,
- o Acknowledgements, and
- o Other real time ATC communications.

Conversation times are relatively short as most conversations are only a few words in length.

When time is not a limiting factor, flight plans are transferred via Service B Teletype. Clearances originating at the ARTCC are relayed via Service F to the ATCT, FSS, or ATCT/TRACON. Current en route and terminal automation programs will eventually provide automatic transfer of flight movement data, via data links between facilities, thus relieving the load on Service F for voice traffic. The introduction of automated data communication will replace many of Service F's current functions.

The intercom network, which handles messages totally within a given facility, is utilized primarily for the transfer of ATC and flight related messages. In addition, it provides a means for setting up assistance and maintenance calls.

C. Switching Systems

Voice switching systems connect ATC controllers or FSS specialists and other controllers and specialists, within a facility (intercom) or other facilities (interphone) via trunk circuits. These systems also provide the user voice interface with FAA owned radio communications and control systems. In addition, access to local support PBX and to commercial telephone networks is provided.

The primary FAA facilities utilizing voice switching systems as of June 30, 1978, are as follows:

FAA Facility Type	Number of Facilities
ARTCC (foreign and domestic)	25
TRACON	218
Towers	496
FSS	319

Virtually all of these facilities utilize Western Electric Company (WECO) equipment leased to the FAA by an AT&T Telephone Company. The primary switching system, which has been in place since 1956, is the WECO 300 Switching System (SS). Developed by the Civil Aeronautics Board, the American Telephone & Telegraph Company, and Bell Laboratories, the 300 system was designed to be "extremely adaptable" and able to handle a large volume of calls.

It consists of racks of relays and switches installed in an equipment room. It also includes modules which provide the interface with ATC operators. These are installed in the FAA equipment console which comprise an operating position. A diagram of the WECO 300 SS is shown in figure 3.8.

The primary parameters of the WECO 300 SS are:

Capacity: 60 to 300 Attendant (controller) positions

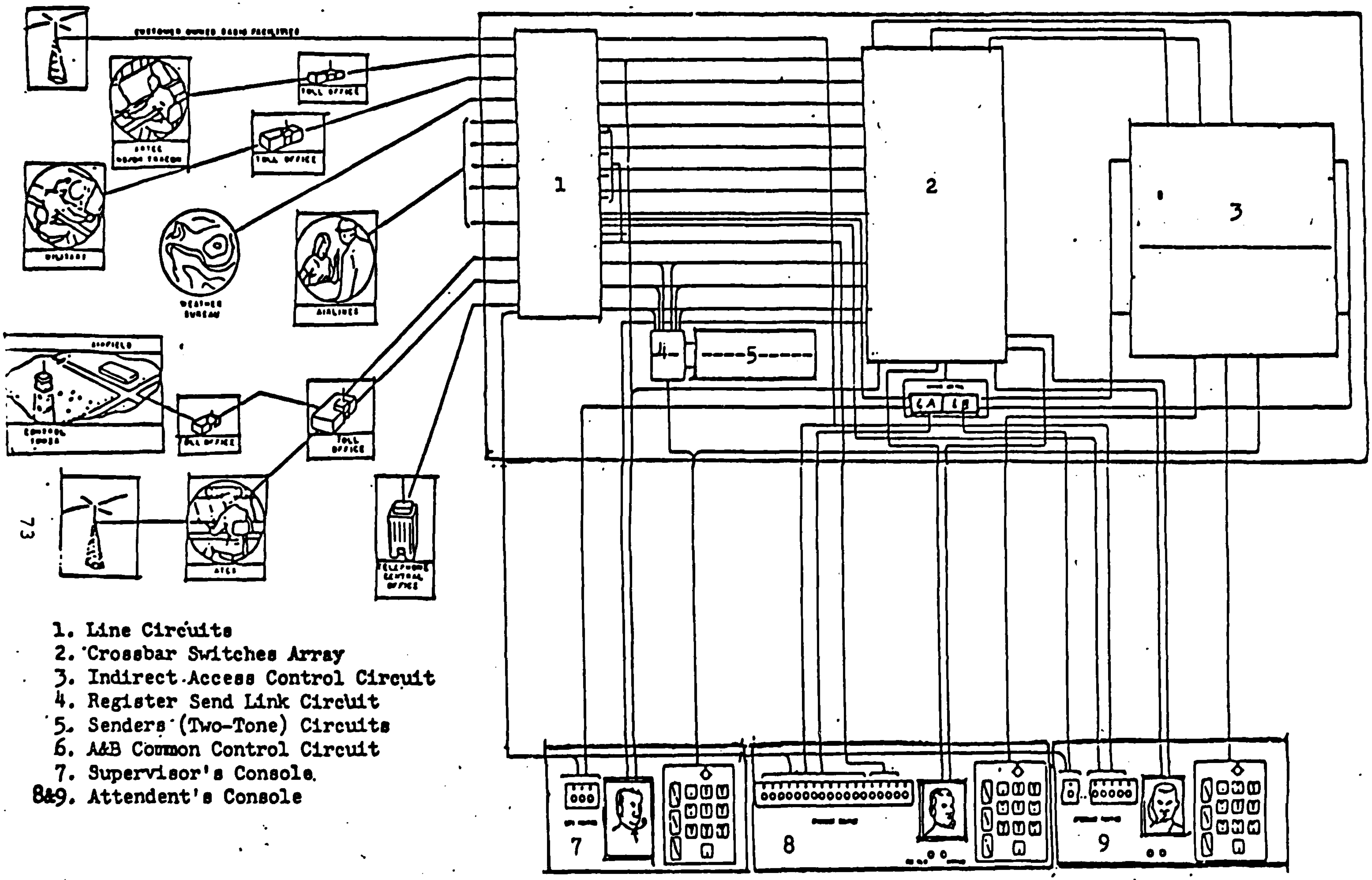


Figure 3.8

Conceptual Block Diagram of the WECO 300 Switching System

Technology:	Hardwired Dual Common Control, Crossbar switches, step-by-step selectors, and relays.
Circuits:	Switching on 4 wire lines only, however, accepts 2 wire lines through hybrids.
Calls-in-Progress:	Unrestricted
Access:	Unlimited to any position/landline radio channel.

The WECO 300 SS is an electromechanical exchange which is capable of interconnecting any of its positions to any of the lines served. The equipment consists of Position Equipment and Back Room Equipment. The former is located at the air traffic controllers terminal and includes a number of keys, lamps, indicators, etc. The Back Room Equipment includes a crossbar switching matrix, relays and control equipment, the distribution frames, trunk/line interface devices, the power supply, and other ancillary equipment.

D. Ground Transmission Links

For communication between FAA facilities, remote terminals, and non-FAA facilities, ground transmission links are required. These links are of two types:

- o The Telephone Company (TELCO) common carrier network, and
- o The leased point-to-point circuits.

The FAA intercom/interphone systems are connected with the local TELCO network via trunks, which allow local calls to be made from and to these facilities. These TELCO trunks also allow long-distance calls, foreign exchange connections, and the in-WATS and out-WATS. WATS (Wide Area Telephone Service) is widely employed where economically warranted, for example, it allows pilots to phone in flight plans from remote locations without paying long-distance charges. Other WATS line applications include:

- o Pilot Automatic Transcribed Weather Answering Service (PARWAS),
- o Military Flight Service (MFS) communications, and
- o Voice Coordination (AFT and BDIS) units.

Leased lines are point-to-point circuits leased from common carriers, which terminate on the FAA voice communications network. The leased circuits conform to FCC tariff number 260 for voice grade private line service characteristics. In addition to being used as point-to-point circuits, these links may also be multi-point, or switched access circuits. The transmission mode may be 2 wire half duplex, or 4 wire full duplex.

E. Voice Switching and Control System (VSCS)

The present switching systems of both the air-ground (RCS) and ground-ground (VCS) communications systems have approached or

exceeded their normal life cycles of 15 to 20 years. In addition, the acquisition over time of diverse equipment has resulted in systems which are costly to maintain, as well as being labor intensive to operate. The systems are largely composed of vacuum tube and electromechanical equipment, which have larger space and higher power requirements, lower reliability and higher response times than that of current solid-state equipment.

To improve the current RCS and VCS switching systems, the FAA is currently evaluating the implementation of a single Voice Switching and Control System (VSCS) with the following capabilities:

- o Increased speed of communications establishment between controllers and aircraft,
- o Increased system flexibility to rearrange services and add new services,
- o Reduced down time through automatic line restoring techniques, and
- o Reduced maintenance costs through the use of automatic monitoring and fault isolation techniques.

The major effect of the implementation of VSCS would be the replacement of the TELCO 300 Switching System with a system which is reconfigurable through the manipulation of software.

Combining both VCS and RCS switching elements into a VSCS system would provide for ease in monitoring, surveillance, and maintenance of the system. Trunk elements would probably be

combined with a universal interface designed to accommodate the various signalling and control elements required during implementation. When completed, a uniform signalling and control scheme will handle both air-ground and ground-ground circuits.

The proposed system relies heavily on a Central Monitor Processor (CMP) to direct communications between distributed microprocessors. The CMP would perform overall switch monitoring and control, and would retain the current state of the system. A System Maintenance Monitor Console (SMMC) on the CMP would permit radio trunk paths to be established, and allow editing of the data base which associates the lines and trunks. The microprocessors would be responsible for call translation and processing.

Current plans for the VSCS include a development system to be under test in 1982, and specifications to be finalized by the end of 1982. Assuming a contract award in 1983, initial installations of the VSCS should take place in 1985.

IV. The Data Communications System

The NAS Data Communications System (DCS) has three components:

- o Ground-to-ground links,
- o Air-to-ground beacon, and
- o Ground based radar.

Within the ground-to-ground data communications category, two subsystems emerge: (1) record data communications, and (2) computer data communication or direct computer-to-computer communication. In this section, record data communication will be described, followed by computer data communication, air-ground beacon, and radar.

A. Record Data Communication

The FAA ground-based data communication system, providing record transfer services, consists of the following elements:

- o Service B,
- o Aeronautical Fixed Telecommunications Network (AFTN), and
- o Modernized Weather Teletypewriter Communications System (MWTCS).

The Service B has existed since the late 1930's, when a limited number of aeronautical radio communications stations were provided with 60-word-per-minute teletypewriters. Through evolu-

tionary growth, each network has been expanded and upgraded to its present configuration. Key milestones in this process were, the start of international communications standardization in 1967 by the formation of the ADIS panel of the Air Navigation Commission of the ICAO, the implementation of an AFTN computerized message switching center at NATCOM, Kansas City in the early 1970's, and Service B modernization in the early 1970's.

In general, the present ground-based data communications system is considered both unsatisfactory and costly. Specialized data communication services have evolved over a long period, with each service satisfying an isolated need. These separate communication networks are largely unable to communicate with each other. Thus, data networks in their current configuration cannot be economically upgraded to the requirements of the NAS.

1. FAA Service B

Service B is a low-speed network which connects all FAA operating facilities, both headquarters and regional, with aviation users. The primary traffic consists of flight plans and aircraft movement messages, exchanged among Flight Service Stations and between Flight Service Stations and ARTCC.

Service B consists of four operationally independent networks of leased circuits and FAA owned terminal units. The four circuit networks are:

- Area B network and supplemental circuits,
- Centers B,
- Utilities B, and
- Computer B.

Table 3-3 shows the FAA facilities which these circuit networks connect.

a. Area B Network

This nationwide network is controlled through a series of polling devices at area relay centers, and the National Communications (NATCOM) facility at Kansas City, Missouri.

The low speed 100-word-per-minute links of this network collect and disseminate information from and to the terminal, while higher speed 1071-word-per-minute links perform intercircuit transfer of collected messages.

The system can be divided between the following three circuit classes:

- Area B - 24 send/receive (S/R) circuits terminating at FSSs, CS/Ts and ARTCCs.

- Supplemental B - 8 circuits which augment the needs of the busier locations without overloading the area S/R circuits.

FAA Facility \ Service B Function	Area B Inc. Supp B	Utility B	Center B	Computer B
ARTCC	✓	✓	✓	✓
CS/T	✓			✓
FSS	✓	✓		
Region CCCs	✓			
FAA Headquarters, CCC/SCC	✓			
NATCOM	✓			
BASOPS		✓		
ARINC/Airlines		✓		
ARO			✓	
NASCOM CCC			✓	
NATCOM (AFTN)			✓	
ATCT				✓
ATCT/TRACON				✓
RATCC				✓
RAPCON				✓

Table 3.3

Service B Connections

- High Speed B (BDIS) - a single transcontinental circuit, at medium speed rate for merging the low-speed data.

b. Center B

This Service B function transfers IFR flight movements and control data between conterminous ARTCCs and the SCC facility. Flight progress data supporting the hand-off of IFR traffic is transferred between centers.

The two 100-word-per-minute teletype circuits which connect all ARTCCs are:

- The Eastern Circuit (GT/9298) with S/R drops to 10 centers and other locations, e.g., SCC, and
- The Western Circuit (GT/9299) with S/R drops to 10 centers and other locations.

These two circuits are connected by the automatic low-speed switch at Kansas City, Missouri. The NATCOM facility transfers messages from one circuit to another. Overseas communications flows through AFTN at the International Aeronautical Telecommunications Switching Center (IATSC), in Kansas City.

This system includes a polling device in each of the two circuits, for communication between

terminals served by one circuit and those served by the other circuit. Thus, a message may be routed to single destinations, multiple destinations, or broadcast through the whole network.

c. Utility B

This group of 100-word-per-minute, half duplex communication circuits, transfers flight plans of IFR flights (both military and commercial) for frequent daily users. Occasional users utilize the FSS, which transmits IFR flight plans via local Area B circuits. High activity Flight Service Stations also use these circuits as an additional route, to transfer information on flight movement, notifications and control messages to and from Military Base Operations Offices (BASOPS). Fifteen multipoint circuits serve ARTCCs, FSSs, BASOPS, Airline operations offices, and non-U.S. manual ARTCCs.

Two types of Utility B circuits exist, I and II. The former are send/receive circuits, while the latter are receive-only at ARTCCs.

d. Computer B

These circuits, installed in the NAS Stage A

ARTS program, connect all ARTCCs and allow the input and output of flight plan related messages. The Flight Data Entry Printout (FDEP) operation, is controlled by IBM 9020 equipment. The flight data processing position has direct access for preparation and modification of the flight plan, which may be entered directly into the system. The majority of circuits are 75 baud (bits per second), however 2400 baud circuits are employed for NAS Stage A and ARTS data communications.

2. <u>Aeronautical Fixed Telecommunications Network</u> (AFTN)

The AFTN is an integrated worldwide teletype communications system of fixed aeronautical circuits. The AFTN system carries communications relating to safety of air navigation and to promote the efficient and economical operation of air services within and outside the continental U.S. This network carries messages of international flight movements and meteorological information at speeds of 60, 67 and 100-words-per-minute. The network extends beyond the continental U.S. to the North Atlantic, Caribbean, Central and South America, Alaska and Pacific regions.

International Flight Service Stations (IFSS) maintain switching units for the network. These exchanges are of

various makes and types, e.g., Phillips DS-714, Phillips ES-3, WU Plan 59, as well as locally assembled units.

AFTN service is divided into two sectors, the North Atlantic/Caribbean area, and the Alaska/Pacific area. The International Aeronautical Telecommunications Switching Center (IATSC) is located in Kansas City, Missouri, and serves to relay meteorological and aeronautical information to the two sectors. AFTN domestic subscribers include ATC facilities, FS stations, military BASOPS, Coast Guard Search and Rescue operations (SAR), National Weather Service, various dispatch services, private cargo and air carrier operations. Foreign subscribers include the switching points of other ICAO nations.

3. Modernized Weather Teletypewriter Communications System (MWTCS)

This low to medium speed data service carries weather related information on meteorological observations and forecasts as well as Notices to Airmen (NOTAMS). Transmission speeds are 100-words-per-minute and 600/1200/2400 bits per second. The network is limited to the continental U.S., and is served by a Weather Message Switching Center (WMSC), located at Kansas City, Missouri. This exchange is a Phillips DS-714 computer-based store and forwarding system which polls all

terminals for collection, storage, selection and distribution of data.

This FAA weather communications system has consolidated and automated the following three services:

- o Service A - an aviation specific service which collects and disseminates meteorological observations, forecasts, NOTAMS.
- o Service C - a general weather service which carries meteorological data of interest to meteorologists, climatologists, and hydrologists of the weather service, military and airline forecast offices. Service C also carries all general public forecasts for distribution by press, radio and TV.
- o Service O - a service for international exchange of meteorological data via domestic land lines, international cable, and radio teletypewriter circuits.

Scheduled and unscheduled messages are transmitted in the system. The former are sent during predefined periods (one message type per period), and are always awaited by WMSC. Unscheduled messages, including reports and updates of data contained in scheduled messages, are entered during prescribed periods of unscheduled data collection. Within these periods, the messages are sent as available.

B. Computer Data Communication

FAA operational efficiency has been improved by computerized automation and direct computer-to-computer information transfer. Using computers to perform bookkeeping functions on each aircraft

from the filing of a proposed flight plan and through flight termination, has reduced the controllers workload and increased the NAS speed of response to changes in traffic conditions.

All static and dynamic data relative to each flight are stored in the central computer complex at an ATCC or TRACON. This includes the FDEP data and flight data received initially from a Service B circuit. The computer processes the data and transfers it to the appropriate controller position in the facility, or to adjacent computers as required. As changes occur, controllers update the flight status directly on the computer.

To fully utilize these features of the NAS 9020 computers installed at ARTCCs and the ARTS systems installed at TRACONs, direct computer-to-computer interchange data has been implemented. The two computer networks are:

- The NAS-NAS data network, which connects adjacent ARTCC NAS 9020 computers, and
- The NAS/ARTS data network, which connects ARTCC, NAS 9020 computers to ARTS computers.

The NAS-NAS and NAS-ARTS data networks both employ 2400 bit per second channels to connect each of the 20 ARTCCs with the adjacent center and with the associated ARTS facilities. These computer controlled networks handle considerable traffic without human action. Links between centers operate at medium speed using voice band circuits and connect directly to the NAS 9020

and the ARTS computer equipment. The Flight Data Entry and Printout (FDEP) terminal associated with the computer facilities and with many control towers, operate at low speed and provide keyboard entry and typewriter output.

The keyboards of the FDEP are polled by the 9020 computer and the entire FDEP operation is computer controlled. The keyboard operator interacts with the computer display prior to gaining transmission access. Once the format is correct, access is requested. Transmission access may be granted at the time of the next poll, or if demand is high, the request is placed in a queue. Once the message is accepted by the computer, it is removed from the display. Output from the computer to the FDEP printout devices are also queued. The FDEP equipment communicates only to the computer, with no provision for switching to other systems or relaying messages. All data is automatically transferred via the computer-to-computer interchange.

With the implementation of this system, aircraft information appears on the controller's display 30 minutes prior to the aircraft entering the sector. Previously, with verbal notification of branch-off, the aircraft appeared on the controller's display only a few minutes before it entered the sector.

C. Air-Ground Beacon

Aircraft surveillance data is the primary input to air traffic control. The Air Traffic Control Radar Beacon System (ATCRBS) provides aircraft position data beyond that provided by radar surveillance. (ATCRBS is also referred to as Secondary Radar - Secra or Secondary Surveillance RADAR - SSR). The ATCRBS consists of airborne transponders, ground stationed interrogators, antenna systems, and processing equipment.

ATCRBS interrogations are transmitted at the rate of several hundred per second using a narrow beam (1^{o} to 4^{o}) antenna, which rotates several times per minute. The interrogation beam asks the questions: "Who are you?", and "How high are you?"

To ask for aircraft identity, two pulses spaced 8 micro-seconds (8μs) apart, are transmitted on the 1030 MHz beam. Transponder equipped aircraft within the beam, reply at 1090 MHz with one of 4096 identity codes. To ask for altitude, a separate pair of pulses spaced 21μs apart are transmitted on the 1030 MHz beam. The aircraft transponder replies with an uncorrected barometric altitude in 100 feet increments. The identity and corrected altitude obtained are then displayed on the air traffic controllers screen. The interrogation and response beam are shown in Figure 3.9.

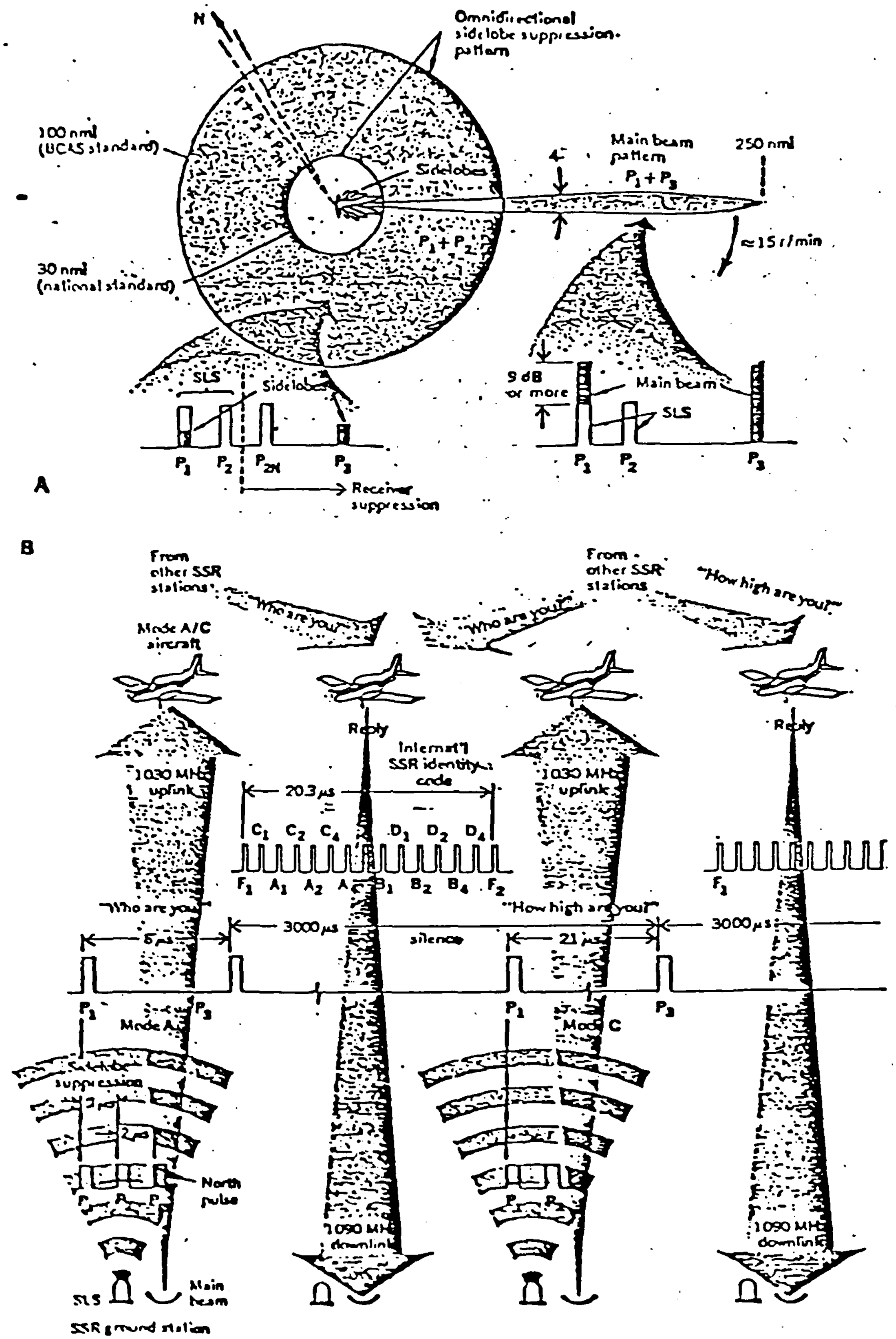


Figure 3.9

Radar Beacon System Interrogation and Response Beams

ACTRBS initially suffered from operational difficulties such as interference, confused target replies, and lack of a sufficient number of transponder equipped airplanes. A Sidelobe Suppression subsystem (SLS) was developed to avoid unwanted interrogation by sidelobes to the main beam, and reflections from obstacles such as hangars. An omnidirectional "suppression" pattern is radiated in addition to the narrow (4°) rotating main beam. When interrogation pulses (P_1 and P_3) are sent out over the main beam, an interspersed suppression pulse (P_2) is radiated on the omnidirectional broadcast pattern between P_1 and P_3. An interrogated plane replies only when the (P_1, P_3) pair dominates the (P_1, P_2) pair, i.e., when the main beam points directly at the aircraft. The problem of nonsynchronous replies was corrected by the addition of "defruiting" circuitry. The initial lack of transponder equipped planes gradually disappeared over time, and no longer exists.

The ACTRBS network consists of 700 ground interrogators or SSR stations that radiate both the narrow interrogation beam and an omnidirectional Sidelobe Suppression (SLS) broadcast on the 1030 MHz link to aircraft within the nation's controlled airspace. The range of the SLS broadcast is about 30 nautical miles (nm). The proposed semiactive Beacon Collision Avoidance System (BCAS) has about a 100 nm sensitivity, and thus numerous 20.3 μs BCAS replies could fit into a 3,000 μs silent period that exists between SSR interrogation.

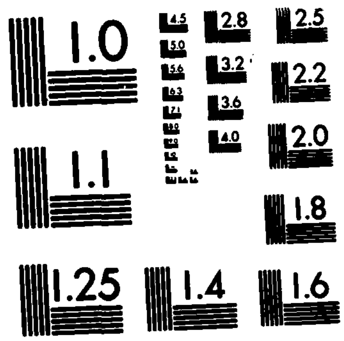
AD-A125 356 SOCIOECONOMIC IMPACT ASSESSMENT: COMMUNICATIONS INDUSTRY PHASE I DESCRIPT..(U) ACUMENICS RESEARCH AND TECHNOLOGY INC BETHESDA MD 22 JAN 79 2/2

UNCLASSIFIED FAA-APO-81-11-VOL-1 DOT-FA78WAI-932 F/G 17/2.1 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

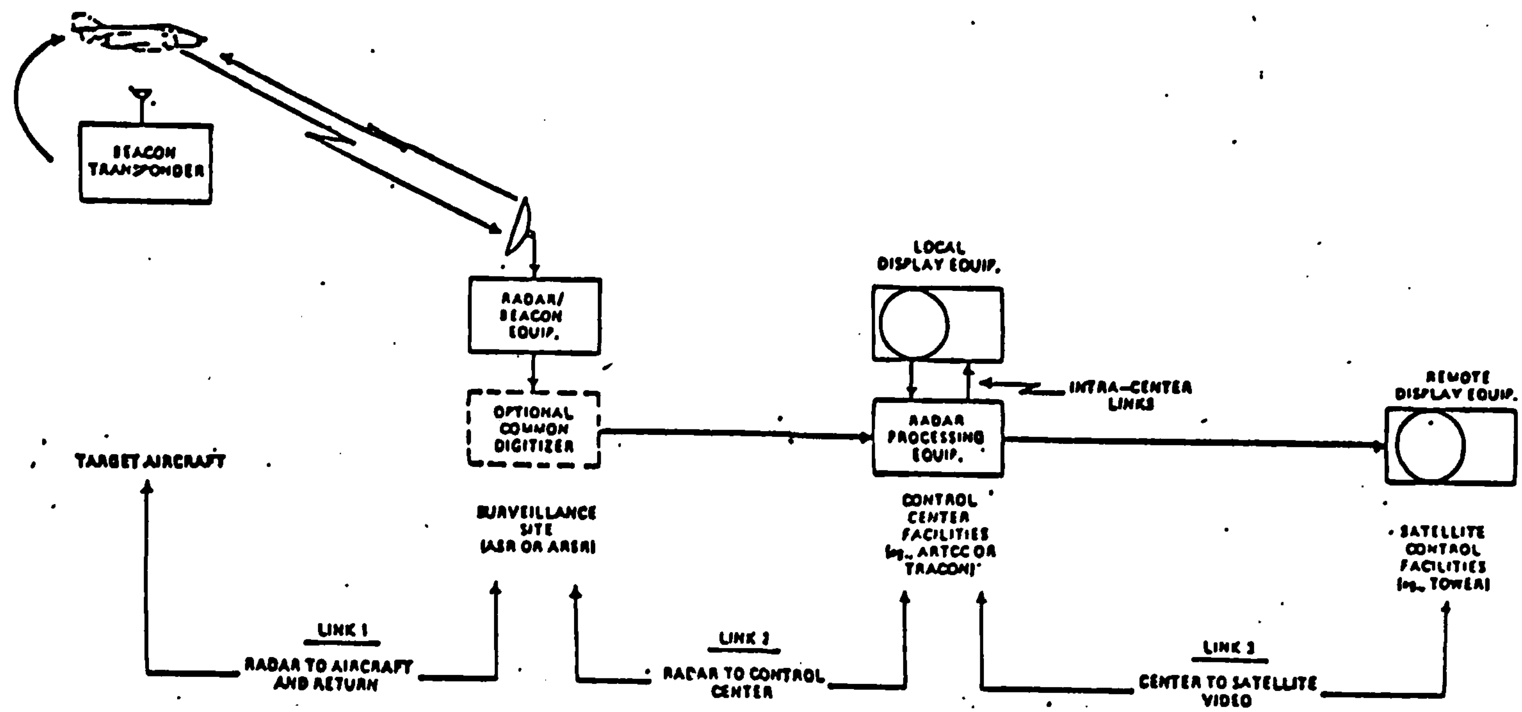
Increases in air traffic and the large numbers of ground interrogators has increased the demands on the system to the point of taxing its viability. The Discrete Address Beacon System (DABS) development effort is currently underway as a replacement for ATCRBS. The principal difference between ATCRBS and DABS is the use of discretely addressed interrogation by DABS. Each aircraft has a unique address, and will reply only to that address once a track has been initiated. By tracking each aircraft and using the unique address capability, DABS is able to schedule interrogations both to minimize uplink transmission rates and prevent multiple responses to a single inquiry.

D. Radar

The FAA radar surveillance system is of two types: for en route ATC, and for terminal ATC. The en route system utilizes Long-Range Radar (LRR) (also called Air Route Surveillance Radar - ARSR), while the terminal system utilizes Airport Surveillance Radar (ASR). Many of the radar sites, particularly the LRRs, are shared with the U.S. Air Force. As of June 30, 1978, there were 104 LRRs and 183 ASRs.

The data links in radar surveillance are (Figure 3.10):

- The two-way ground-air-ground link from the radar site to the aircraft and the reflection or beacon reply code. This link is used in all installations, both en route and in terminal areas.



Major Surveillance Information Transfer Links

Figure 3.10

- The link in the surveillance or radar site to the control center where the detected radar or beacon reply is processed and displayed.
- The video or display link, in which a processed video display is transmitted from a hub airport to a tower in a satellite airport tower or facility.

Radar and beacon data transmitted from the surveillance site is either analog or digital. For NAS Stage A (Models 1 and 3) and ARTS III installation, digital transmission on three 2400 baud lines is used. Continuous analog information is provided on NAS Stage A (Model 2) and all other terminal surveillance systems.

Where digital transmission is employed, radar or beacon preprocessing is performed at the radar site. After preprocessing by digitizer equipment, target messages of 65 bits are transmitted over 2400 baud lines to the data receiver group of the common digitizer. Because of differences in target detection and decoding, message format is performed in the common digitizer.

The link between the radar site and control site is a Radar Microwave Link (RML) operating in S-band. The circuit lengths involve up to ten relays. The links are four-channel for transfer of radar data and two-channel for control data transfer.

The terminal facilities use ASR surveillance for the short-range coverage near airports. The display of ASR information may be transmitted from an approach control facility to control

towers located at airports receiving hand-offs from that facility. The microwave link terminal at the parent facility converts both the primary and secondary radar data that is available at the facilities operating console to a high resolution (945 line) TV presentation of both range and azimuth. The display is transmitted to a satellite control tower via the associated microwave links.

E. National Airspace Data Interchange Network (NADIN)

Over the past decades, the FAA has created a number of entirely separate low speed data services for collection and dissemination of information to and from its facilities. Each of these services is applied to a specific area, and suffers from obsolescence, limited expansion capability, and high operation and maintenance costs. In addition, communication between these networks is not possible, and they cannot be combined to meet NAS present or future data communication requirements. The deficiencies of current discrete record transfer networks are:

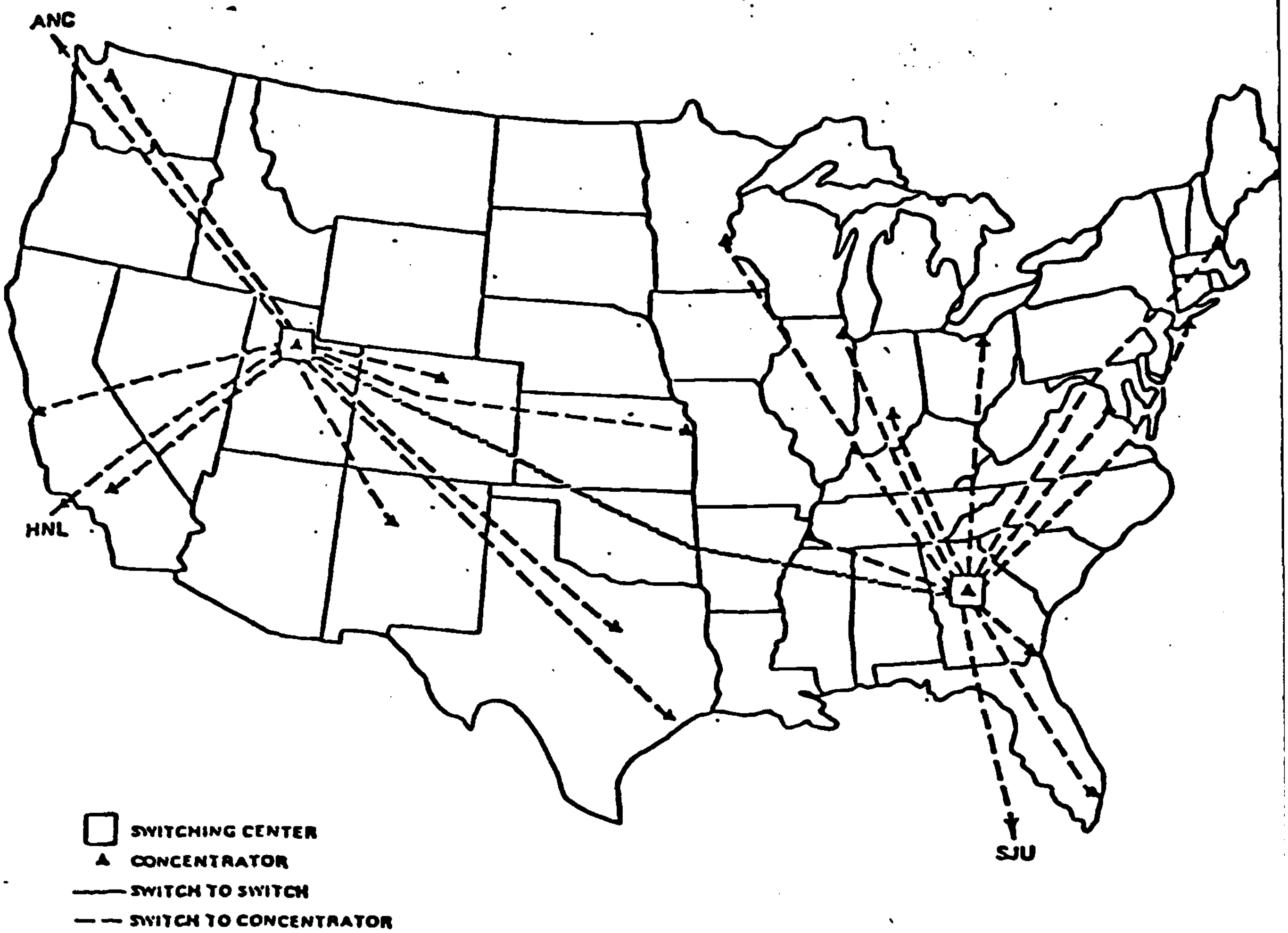
- Excessive circuit cost,
- Obsolete equipment which is difficult to maintain,
- Labor intensive operation and maintenance,
- Incompatible formats and procedures, and
- Inadequate network management.

In the early 1970's, the FAA conceived NADIN as a fully integrated-state-of-the-art ground-to-ground data network to meet total projected requirements of Air Traffic Control. NADIN will establish uniformity of equipment and procedures and attain a margin of capacity and performance for both current data communication requirements and future needs.

The NADIN system will consist of a nationwide, low speed message switching network, whose backbone links are shown in Figure 3.11. These include two Message Switches, located at the FAA ARTCC facilities in Salt Lake City, Utah, and Atlanta, Georgia, and a number of Concentrators, one located at each ARTCC, and at Anchorage, Honolulu, and San Juan.

The concentrators will be connected to the two Message Switching Centers, each of which will be capable of individually and independently managing and providing service to the entire network. Each local concentrator will control a number of data communication terminals and the NAS 9020 computer terminals.

All messages initiated at a terminal pass through the concentrators, arrive at one of the Message Switching Centers, and are delivered to the desired destination. These switches also perform a Data Journaling function, to allow a follow-up in case of a lost or garbled message. They also maintain complete statistics on the traffic handled, making available continuous information



NADIN BACKBONE NETWORK.

Figure 3.11

on network demand and capability. These statistics pinpoint under-utilized circuits and congested areas, and allow implementation of dynamic trunk supervision for optimal utilization.

The NADIN system will be designed and implemented to provide the following capabilities:

- o Transfer of all messages presently being handled by the FAA Service B network,
- o Transfer of all messages presently being handled by the FAA controlled portion of AFTN, and
- o Communication with the Weather Message Switching Center (WMSC), Common ICAO Data Interchange Network (CIDIN), Aviation Weather and NOTAM System (AWANS), Central Flow Control, Air Carrier Communication Systems, National Weather Service (NWS), Meteorological and Aeronautical Presentation System (MAPS), and the international Aeronautical Fixed Telecommunications Network (AFTN).

The NADIN I system will consist of a number of hardware elements, including:

- o Switching centers,
- o Cencentrators,
- o Modem
- o Circuits
- o Special Interface Services, and
- o Terminals.

These hardware elements are designed to improve collection of ATC statistical data from field facilities and to allow

systematic growth for the handling of aircraft movement and control data. The appendix to this report contains detailed information on these hardware elements, as well as more information about the proposed NADIN system.

The first version of the NADIN system, or NADIN I, is expected to be in development from 1979 until late 1981. Thus, the first field cutovers to NADIN I will likely occur in 1982. By 1985, expanded and enhanced NADIN systems should be well under development.

V. Projected 1985 FAA Communication System

From a review of the present system, research and development underway, and new developments in the facilities service area, it appears that the basic structure of the FAA communications system will not change by 1985. The division of facilities into en route, terminal, and flight service functions will persist. Modernization and automation increase will likely occur as discussed below.

The NADIN I system is expected to be implemented by 1982. With the release of a Request for Proposal in February 1979 and a contract award in September 1979, the system is forecast to be developed by November 1981, and operating in the field by 1982. Thus, by 1985 some enhancement of the NADIN should have occurred. Flow control will probably be entirely on the NADIN, FDEP should be well underway or changed over, all weather data circuits will be converted, and the ARTS will be converted. The myriad of diverse data circuits will be disappearing and a single data communications system will be growing as new uses are developed. ATC operational procedures also will be changing and the silent hand-off with little or no verbal coordination is expected to be the norm.

The Voice Switching and Control System (VCSC) program is

currently not at the same stage as NADIN, thus projections for this system have less validity. Several major approvals are still required:

System Requirements Statement	- expected to be signed in February, 1979,
Acquisition Paper	- completed by July 1979, assuming approval,
Procurement Request	- completed by September 1979.

Thus, it is expected that a contract will be awarded by June 1980 for a development system to be evaluated at NAFEC. A system could be under test in 1982 with test results integrated into a procurement specification by late 1982. A production contract award could then be expected by June 1983 with an initial installation being completed by 1985.

From the past history of modernization efforts, it is expected that VSCC will be installed at an ARTCC first. Implementation will probably proceed for all centers with terminal area installations starting in the late 1980s. The FSS portion wil depend heavily on the consolidation or Hub FSS decision expected about 1982. If consolidation is not approved, less emphasis will be given to VSCS for FSS and no FSS/VSCS would be installed. If consolidation is approved, FSS/VSCS installations would probably occur simultaneously with terminal installations in the late 19f 's. The lollar and manpower savings expected with the FSS con...idation program and the VSCS program tend

to favor doing both, such that a VSCS ARTCC system can be expected to be installed by 1985 with installations continuing for all 20 ARTCCs, with both terminal and FSS systems being converted to VSCS by the late 1980s.

In the technical control or Remote Maintenance Monitoring (RMM) area, no totally integrated system approach is expected to evolve. Instead, various efforts will be undertaken to add RMM capability to solid state type equipment as it is initially installed or as vacuum tube equipment is replaced. The current remote maintenance monitoring program for RCAGs will be completed by 1985. Efforts underway to modernize VORs also include RMM; thus this remote capability should be installed by 1985. The VSCS will include remote monitoring and control for VSCS hardware. Other RMM systems for the Air Route Surveillance Radars (ARSRs) and terminal remote receiver and transmitter sites will be in the acquisition stages. Concurrently, the Airway Facilities Service field organization will be changing towards the larger consolidated facilities that RMM will allow.

The collision avoidance and conflict resolution areas will undergo changes between now and 1985. Initially, it is expected that procedural changes will occur such as expanding the Positive Control Areas by lowering the floor. Increases in both number

and sizes of Terminal Control Areas will also probably occur. Beyond that, elements of a hardware system are likely to be:

- A National Standard for BCAS is planned by late 1983, BCAS could be in the initial implementation stage by 1985.
- DABS plans indicate that given an implementation decision in early 1980, sensor delivery should begin in mid 1984. Thus the Discrete Address Beacon System would also be in the implementation stages by 1985.
- ATARS schedule parallels that of DABS with an implementation decision in April 1980 and release of a Technical Data Package in April 1982. Thus ATARS would be in the implementation stage in 1985.

Since a data link is essential to the ATARS program through DABS, the foregoing must be tempered with a historical pessimistic view. Delays can be expected in a changing technical environment that also engenders changing operational requirements. Thus, the forecast of a 1985 implementation could easily slip. With the intense pressure being applied by Congress and industry due to the San Diego midair collision, a slip beyond the late 1980s is unlikely.

The Small Voice Switching System (SVSS) should be installed in some towers by 1985. With the program well underway and a specification published, the planned delivery of an engineering model in early 1980 seems feasible as does completion of a procurement Technical Data Package (TDP) by late 1980. How many towers will have the SVSS installation complete by 1985

is unknown at present. SVSS systems will probably be installed for a mixture of new towers and replacement of older systems.

In general, the difference between the present system and the 1985 system appears to be primarily increased automation, consolidation of the functions, and the replacement of obsolescent equipment. More use will be made of computers to (1) reduce the workload on ATC controllers, FSS specialist and maintenance technicians; and (2) to provide features not currently provided, such as traffic data compilation, automatic service restoration, and more automatic switching. FAA circuit miles will be reduced by the NADIN system. Increased reliability and maintainability will occur from both technology upgrading and also from RMM automation efforts.

While the above assessments represent current information about the projected 1985 NAS communications system, the history of aviation communications is replete with instances of technological innovations which occurred either faster or slower than expected. The time lags in achieving technological changes in aviation communication systems are discussed in Chapter 4.

CHAPTER FOUR

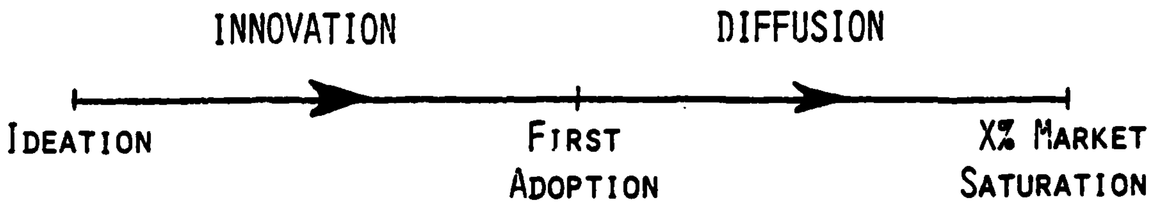
TECHNOLOGICAL EVOLUTION IN AVIATION COMMUNICATIONS

It should be clear from the last three chapters that aviation communication systems evolved over time with a close correlation with dynamic changes in communications technology. However, the evolution has not always been as orderly and smooth as it may appear to those who have no been deeply involved in the development of aviation communications. To realistically forecast aviation communications technology into the future as a function of regulatory policies, it is desirable to have some understanding of the relevant evolutionary process. The purpose of this chapter is to develop this understanding through an examination of several case histories and some conceptual generalization.

I. Concepts and Definitions

The literature of technological change [75, 77, 85, 93 and 98] does not offer a standard terminology. For the sake of clarity, this section presents the terminology and concepts which will be used in this project. Conceptually, the technology evolution process may be divided into the two stages of innovation and diffusion. As shown in Figure 4.1, the innovation state begins with ideation, the energence of a new idea of a physical device or technical practice, and ends with the first adoption of that device or practice [20]. Typically the innovation stage takes place within a single firm. The

TECHNOLOGICAL EVOLUTION



More Detailed Breakdown:

INNOVATION	DIFFUSION
Ideation	Intraindustry
Invention	Interindustry
Performance Criteria	Intersectoral
Preliminary Engineering	Interregional
Prototype	International
Specifications	
Costing	
First Order	
First Delivery	
First Adoption	

Figure 4.1

Stages of Technological Evolution

diffusion stage begins with the first adoption and proceeds with the adoption or adaptation of the same device or practice by other firms and users in the same industry, other industries, and in other countries. The diffusion stage nominally ends when the industry or market is saturated with x % of the firms and/or users having adopted the innovation [65]. Innovation lag is the elapsed time between ideation and the first adoption. Diffustion lag is the elapsed time between the first adoption and when y % of the firms and/or users in a particular industry or country have adopted the innovation, where y may be defined as a function of x. For example, if $y=\frac{1}{2}x$, diffusion lag is the time for half of the firms in an industry which are expected to adopt the innovation to have actually adopted it.

For this project, a distinction will be made between the electronics industry, the communications industry, and the aviation communications industry. In general, new technology tends to diffuse from the electronics industry to the communications industry, and then to the aviation communications industry. This is especially true for the technologies in the VCS and DCS categories of aviation communications since they are ground-based and are frequently leased by the aviation sector from communication companies. However, as shown in Figure 4.2, there is often a direct path of technology diffusion from the electronics industry to the aviation communications industry.

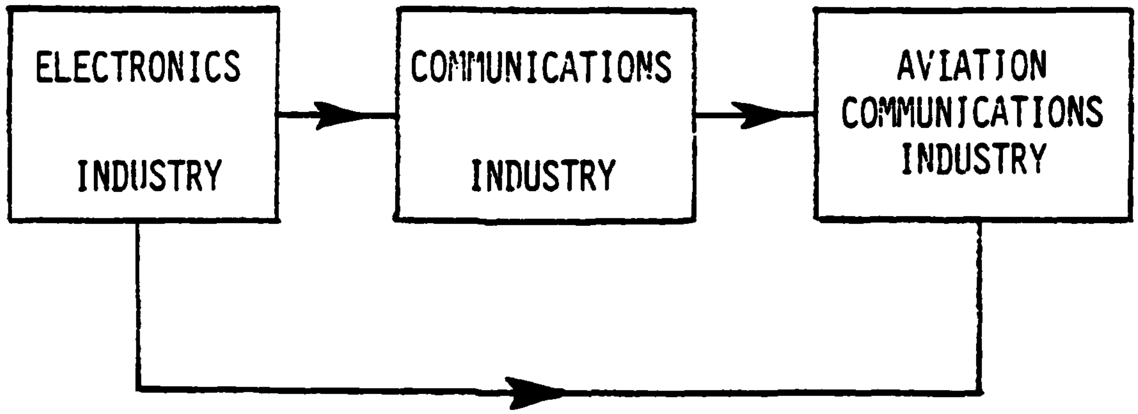


Figure 4.2

Paths of Interindustry Technological Diffusion

Many of the new technologies found their ways to the RCS category of aviation communications through this path of diffusion.

Another useful concept of technology innovation and diffusion relates market forces and regulatory policies to technology as shown in Figure 4.3. "Technology push" represents partly the engineer's interest in the application of newly discovered scientific principles, and partly his interest in spreading the application in many areas, including aviation communications. "Society pull" represents partly the demand for new technology to reduce the cost or improve the quality of goods and services on the market, and partly the demand for novel goods and services created by new technology. The interactions between technology push and society pull, which result in technological changes, are tempered by governmental regulations, which may accelerate or retard specific technology innovation and diffusion in sectors of industry and society.

Applying the above concept in the review of the historical development of aviation communications, three classes of technological innovation emerge:

1. <u>Evolutionary Innovations</u>

These innovations are brought about by changes in technology that result in the reduction of weight, size and power requirements,

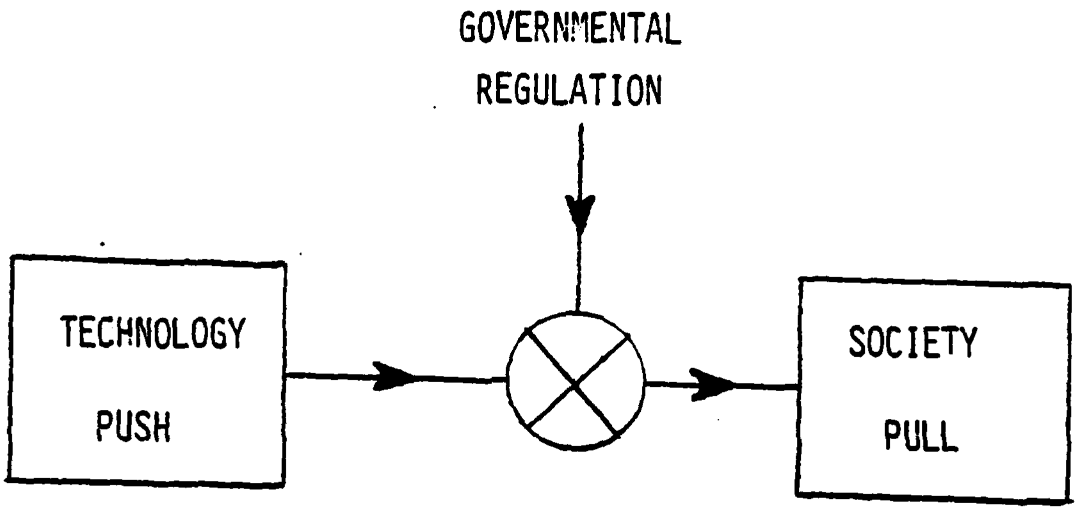


Figure 4.3

Technological Changes Affected
by Governmental Regulations

or the improvement of operational features. This outcome was obtained by the substitution of semiconductor devices for electron tubes in aviation communications systems. Often the evolutionary process provides an entree for new concepts to be "grafted" onto the old. As examples, doppler VOR was grafted onto VOR, and the air-ground-air data link was grafted onto the voice communications system. Another example is the doubling of VHF communications channels by halving channel bandwidths, which resulted from pressures for spectrum conservation and new technology.

2. Planned Innovations

These result from attempts to meet foreseen operational requirements by the development of new systems utilizing current technology. Some planned innovations are complex large-scale systems, such as the Microwave Landing System (MLS), and require substantial development efforts, while others are more easily achieved smaller-scale systems.

3. Forced Innovations

These innovations are brought about generally by regulatory edict and public pressure (generally through Congressional action). Examples are crash recorders, Emergency Locator Transmitters (ELT), and the Ground Proximity Warning System (GPWS).

The concept of technology diffusion has been widely used in communications. For example, in the early 1920's approximately

30 % of U.S. households had telephones while today the figure is 94 %, indicating widespread diffusion has been achieved. Cable television is just about halfway to market saturation. In the field of aviation communications, there are many examples of technology diffusion:

a. Close to 100% of all aircraft carry communications equipment. Although newer planes carry solid-state systems, a large proportion of the older planes have been retrofitted with solid-state communications equipment. However, communications equipment using electron tubes will be flying for many years to come.

b. The price of a good Inertial Navigation System (INS) is quite high (on the order of $100,000); consequently, not too many have been installed. However, the new Minneapolis-Honeywell Laser Inertial Navigation System (LINS) is being flight tested. This new system is expected to be highly reliable and is estimated to cut the cost of ownership by about one-half over that of gimballed-gyro systems [72]. These features should open new markets.

c. A third example is provided by recent figures from the Airplane Owners and Pilots Association indicating that of 180,000 general aviation aircraft, 110,000 carry beacon transponders and 45,000 carry Mode C altitude encoders. One can speculate that the future growth of beacon transponders in general aviation will depend upon FAA Air Traffic Control pro-

grams and policies. These include the requirement of transponders under Instrument Flight Rules (IFR) and high-density traffic conditions, and the future implementation of the Discrete Address Beacon System (DABS). The cost of the user-required airborn transponder equipment will continue to play a role as well.

In general, technology forecasts tend to focus on state-of-the-art technologies in a given field, and therefore pay more attention to technology innovations. Technology assessments are concerned with the extent of social impacts of technology, and therefore pay more attention to technology diffusion. In the current project, however, the diffusion of technology from one industry to another (*see Figure 4.2*) is important in technology forecasts. Thus, both technology innovation and diffusion in aviation communications are of interest although the former is more prevalent in the literature.

II. Case Histories

The aviation communications industry has long been interested in technology innovations. For example, the radio Technical Commission for Aeronautics (RTCA), an association of aeronautical organizations of the United States from both government and industry, devoted its 1976 annual conference to the theme, "RTCA Explores the Regulatory Process, Operational Considerations and

Economics of Getting New Technologies Implemented in the Air Traffic Control System." [86]. One Session of its 1978 conference [87] was entitled, "Practicality of Orderly Implementation."

The four case histories presented below were complied on the basis of a literature review and interviews with people experienced and knowledgeable in the recent successes and failures in the adoption of new technologies in aviation communications.

A. Success of an Evolutionary Innovation

The first case history relates to the introduction of transistors, or more specifically, semiconductor devices, into aviation communications. A historical perspective [11] is in order:

1919 - Passenger air transport service between London and Paris made use of air-ground radio telephone equipment designed and installed by Marconi's Wireless Telegraph Co.

1926 - Varney Air Lines inaugurated the first commercial air transportation service in the U.S. (Pasco, Washington-Boise, Idaho - Elko, Nevada).

1928 - Regular passenger schedules were introduced in the U.S. This year also marked the beginning of experimental radio installations in U.S. aircraft.

1929 - The first Federal Radio Commission hearing on aviation radio took place.

1932 - "... coincident with the completion and perfection of the radio system in 1932, we find that the exclusive mail plane with its pilot and his parachute had disappeared and passengers and mail fly together. Without the radio communication system, furnishing continuous means of communications between ground and aircraft, mail and passengers could not have been combined... ." "The mobile radio service to aircraft is conducted by radiotelephone. It is a service operated entirely for the safety of life and property. No public message traffic is handled. Air-to-ground communication is, of course, dependent upon radio. The frequencies used during daylight hours are between 4900 kc and 6000 kc and during dark hours between 2850 and 3500 kc. Radiotelephone is used to allow the pilot to converse directly with the dispatcher on the ground. The use of separate frequencies for day and night is necessary on account of transmission characteristics of the frequencies. Both the aeronautical aircraft stations use the same channel so that over a length of airway you have in effect the equivalent of a party line telephone circuit thus conserving frequencies." [48]

1936 - The following compulsory regulations were issued by the Air Regulation Division of the Department of Commerce:

"During visual or contact flying in hours of darkness or daylight when operating over airways on which radio range beacon ground facilities have been established, a radio beacon receiver system, capable of receiving radio range beacon signals, weather broadcasts and emergency messages shall be installed."

"If such radio range beacon reciever system fails en route, the flight may proceed to a terminal during definitely favorable weather conditions provided the airplane is equipped with a two-way plane-to-ground radio telephone system capable of receiving weather reports and emergency messages."

"When operating over airways on which radio range beacon ground facilities have not been established, a visual ground-to-plane signalling system approved by the Secretary, amy be used in lieu of the aforesaid radio range beacon receiver system."

"on or before January 1, 1936, a two-way plane-to-ground radiotelephone communications system, independent of radio facilities provided by the Department of Commerce, capable of receiving at least weather reporting and emergency messages shall be provided by the operator."

1938 - Flight test of VHF air-to-ground communications was begun by TWA for the airline industry, in daily operations

between Pittsburgh and New York utilizing airlines-Bell Laboratories equipment. TWA reported that VHF communications were completely unaffected by precipitation static, heavy rain static and heavy thunderstorm static.

1942 - The military took over production of airlines' VHF communication sets. These became the famous ARC-1 sets used in World War II.

1947 - Airlines first contracted with electron tube manufacturers for improved tubes. Airlines specify a list of ten preferred miniature tubes to be used in all future airborne equipment.

1950 - Airlines required additional Air Traffic Control VHF frequencies and consequently all ARC-1 sets were modified for 50 channels. (The original sets had only four channels).

1951 - The airlines expressed the need for 50 kHz communication channel spacing. (It has recently been reduced to 25 kHz).

These salient points emerge from this historical perspective:

- A transition from the high-frequency (HF) bands to the very high frequency (VHF) bands. This move resulted in less atmospheric noise and the use of much smaller antennas.

- There were reliability problems with electron tubes, chiefly from degradation and application problems.

o There was a demand for an increased number of communications channels. (From 4 in 1946 to 50 in 1950).

A major innovation which held much promise for the reduction of weight, size and power requirements for aviation communication systems was the transistor. Invented at Bell Laboratories in 1947, the transistor evolved from the point-contact type to the alloy junction type in the early 1950's. The initial applications were as replacements for subminiature tubes in hearing aids. In the late 1950's they were being used in portable broadcast sets. It was not until the early 1960's that the transistor started to be used in aviation communication systems. In part, this was the result of the development of the planar process used in the fabrication of semiconductor devices. This made possible higher frequency applications and increased power dissipation both of primary concern to equipment manufacturers in the design of new airborne avionic systems.

Arthur Wulfsbert [97] points out that the innovative process in aviation communications is extremely complex and a need exists for a high degree of interaction between problem exploration and knowledge exploration. Neither a single-minded devotion to market research nor an emphasis on technical development and awareness is likely to be sufficient for success. It is the subtle combination of both that seems to work. He cites the following pertinent example:

In the early 1960's Collins Radio Company (now a part of Rockwell International, Inc.) introduced a new line of airborne communications and navigation recievers called the "Triple-S" line (for Solid State Systems). These receivers, which proved highly successful, incorporated three major innovations:

- o Elimination of all electron tubes, made possible by advances in transistor technology,
- o Elimination of motor-driven tuning mechanisms, made possible by the development of electrically variable capacitors, and
- o Elimination of mechanical rotary switches, through the use of high-performance switching diodes developed for use in computers.

Were these innovations driven by the known needs of the market for improved reliability and lower power consumption, weight and cost? Or were they driven by the emergence of new technologies and someone asking the question, "How can we apply these interesting new devices?" The answer must be that knowledge of, and concern for, market needs and knowledge of new technology and curiosity about potential applications were present. Both technology push and society pull were at work.

The main idea derived from the case history of semiconductor devices is that, where governmental regulations play a minor role, market competition is the main force behind evolutionary innovations. Under these circumstances, it is often smaller companies (like Collins) which take the lead. Con-

sequently, today the new solid-state VHF communications transceivers provide 720 (25 kHz) channels; they are 25-30% cheaper (adjusted for inflation) than the sets they replaced; they are three times more reliable than the older sets, having a mean-time-to-failure (MTBF) in excess of 4000 hours; their weight and power consumption is about half that of their predecessors; and they have both data link and voice communication capabilities.

B. Three Success Stories of Planned Innovations

In the area of planned innovations, special accolades were expressed in the literature for three systems: FAA's Automated Radar Terminal System (ARTS III), their Minimun Safe Altitude Warning System (MSAW) and the Microwave Landing System (MLS) [59].

The basic ARTS III system consists of three major subsystems: data aquisition, data processing, and data entry display [18]. The ARTS III system provides automatic and continuous association of the data pertinent to a controlled aircraft and its radar video on a controller's display. These data consist of aircraft identification, altitude (provided the aircraft is equipped with a Mode C altitude encoding transponder), and computer derived ground speed. Thus, ARTS III systems have increased the utilization of the radar beacon system through the use of the identity and altitude information features of the system. The ARTS III system also provides for

automated transfer of the information required for coordination between controllers through simple keyboard entries.

The implementation and installation of 64 ARTS III systems was accomplished with a minimum of confusion and delay. Contributing to this performance was good background planning, well prepared specifications and strong contractor performance, although the program was not without its rough spots, and "interference from outside sources" [59].

The Minimum Safe Altitude Warning System (MSAW), a software additon to the ATC Radar Beacon System, was developed and introduced and is now being used effectively. An important factor was that no new associated airborne equipment was required, and that the changes could be introduced by means of software modifications [59].

The Microwave Landing System (MLS) is also considered a well planned and coordinated program. The concept of instrument landing systems (ILS) goes back to 1919 when the Bureau of Standards made use of a direction finder in an aircraft in conjunction with a ground-based beacon to locate the landing field [58]. No further development took place until 1928 when the Bureau of Standards made further improvements.

The first commercial VHF/ILS was demonstrated in 1939 at Indianapolis, and was adopted for use in the U.S. in 1941. The International Civil Aviation Organization (ICAO) adopted it as

a standard in 1949 and it is protected by international agreement until 1985. Most likely this protection period will be extended for a ten-year period. There are more than 600 ILS installations in the U.S., of which 56 allow operations at less than 200 feet, and 4 at less than 100 foot ceilings. ILS has had some problems: it restricts arriving aircraft to a single flight path, has limited channel capacity and, it cannot be employed at mountainous sites [62].

MLS was initiated as the result of a letter from the Air Transport Association (ATA) to the FAA in 1967. In December 1967 the Radio Technical Commission for Aeronautics (RTCA) formed a special committee (SC-117) to explore the feasibility of a universal approach and landing system that would satisfy the needs of several classes of users for years to come. Over 465 experts contributed to the SC-117 report, "A New Guidance System for Approach and Landing," published in late 1970. This was followed in July 1971 by a fully coordinated National Plan by the FAA for development of the MLS. The Plan was jointly sponsored by the Department of Transportation, the Department of Defense, and the National Aeronautics and Space Administration. The Federal Aviation Administration was designated to lead the three phase program:

Technique Analysis and Contract Definition: Each of the six competing contractor teams was required to define a completely integrated system. This effort, eompleted in late 1972,

resulted in a feasibility model demonstration program, test and evaluation criteria and a prototype system-validation program.

Feasibility Demonstration: The field demonstration and testing of feasibility hardware took place in 1973 and 1974 at the FAA National Aviation Facilities Experimental Center (NAFEC) at Atlantic City and NASA Wallops Island Flight Center in Virginia. Four contractors selected from the first phase ground and flight-tested their respective systems (ITT and Bendix at NAFEC and Texas Instruments (TI) and Hazeltine at Wallops). Two of the systems employed the scanning beam technique (Bendix and TI); the other two made use of a doppler technique (ITT and Hazeltine). Intensive evaluation led to the selection of the time-reference scanning-beam (TRSB) approach with Bendix and TI chosen as the contractors for the prototype development and evaluation phase.

Prototype Development and Evaluation: Both contractors built two systems designated "small community" and "basic narrow aperture" types. The small community system was designed to provide a low-cost landing system for small airports while the basic-narrow-aperture system was designed for use at airports with up to 8000-ft runways.

ICAO, during the same period, examined the suitability of MLS for international standardization. ICAO member states

submitted proposals: the United Kingdom, a doppler system, Australia, a TRSB system, the Federal Republic of Germany, a DME (Distance Measuring Equipment) based system, France, a sound-derived system, and the U.S. submitted its TRSB system. The French proposal, not being complete, was withdrawn. In March 1977, the TRSB MLS was recommended for adoption. However, there was considerable debate among the proponents of the doppler, TRSB and DLS systems, which included a U.S. Congressional hearing. Tests on the doppler and TRSB were held at several locations in this country and abroad. In April 1978, ICAO adopted the U.S. TRSB system as the world standard.

FAA experience [14] is that the government acquisition cycle requires from 7 to 9 years for a major system to become operational after a requirement has been identified. Some of the activities include the initial planning review conferences with inputs from the aviation industry as to the activities and systems which have the greatest potential for satisfying future needs. A budgetary cycle involves the FAA, the Department of Transportation, the Office of Management and Budget (OMB), the House and Senate, and finally an Appropriations Act is submitted for Presidential approval. Even after approval, OMB can impose budget limitations. Five years is often required to reach this stage before contracts can be let, and 7 to 9 years may elapse before the system is commissioned for use. Although this process

is simple and straightforward, it does not take into consideration the R&D program, nor user acceptance and international standardization. In the case of MLS, assuming everything falls into place, installation of 10 ground systems should be completed by the end of 1980 (13 years after the identification of the initial requirement), with additional installations taking place at the rate of 6 to 10 per month until implementation is completed.

The main idea derived from this case history of successful planned innovations is that, in the case of ground-based equipment and systems, the responsible government agency must do the planning and coordination, and involve all the affected parties from the conceptual planning stage through the execution phase. The time required will depend on the sophistication of the technology and the number of affected parties. However, government agencies can do an excellent job and have demonstrated their capabilities in many successful cases.

C. An Eventual Success After a False Start

This case study relates to Collision Avoidance Systems (CAS). A chronology of CAS development follows [96]:

1955 - A joint RTA-Institute of Radio Engineers meeting was held on Collision Avoidance.

1956 - Collision of two airliners over the Grand Canyon spurs the Air Transport Association (ATA) to have a special meeting. Collins radio proposed an airborne doppler approach to the problem, but later dropped it.

1956 - Dr. J. S. Morrel of Bendix Radio provides the first accurate description of the physics associated with collision avoidance.

1960 - McDonnell-Douglas develops a time-frequency Collision Avoidance System.

1962 - FAA establishes a Collision Avoidance Advisory Group.

1967 - ATA Report No. 117 was published. ATA asks FAA to conduct a real time simulation of CAS and ATC to see if CAS would adversely affect ATC; to start a National Standard for collision avoidance; and to begin an international standardization program.

1970 - ATA is satisfied with the results of the demonstration program and asks FAA support for making time-frequency CAS a National Standard and for proceeding to early implementation. The ARINC 587 specification for time-frequency CAS was published.

1971 - Senate Bill S-2264 was introduced requiring installation of CAS on certain types of aircraft. ATA formally requests FAA to adopt time-frequency CAS. House and Senate hearings were held at which other manufacturers suggested that FAA should look at other systems.

1972 - FAA starts evaluation of Minneapolis-Honeywell and RCA time-frequency systems.

1973 - FAA, NAFEC studies ATC-CAS systems in terminal areas.

1974 - Rep. Barry Goldwater, Jr., criticizes FAA for its opposition to airborne CAS (ACAS). FAA recommended to the Senate that it not make ACAS mandatory; while GAO urged FAA to expedite its evaluation of CAS. Minneapolis-Honeywell announces its system is ready to go; RCA drops out.

1975 - FAA requests MITRE to begin development of an ACAS using ATCRBS (ATC Radar Beacon System). MITRE begins flight testing of BCAS (Beacon-based CAS). FAA announces that life cycle costs of the three ACAS systems were estimated to vary from $600 million to more than $800 million depending on the system selected, and that ACAS was not as attractive as BCAS which would make use of existing beacons (more than 100,000 transponders have been installed, including more than 45,000 with altitude reporting).

1977 - FAA sets up a BCAS design team to formulate a BCAS concept that would work in all airspace and all traffic environments and would minimize interference with ground ATC surveillance and ATC control systems.

1978 - The BCAS concept is published by FAA [64].

The problem of providing adequate protection against collisions reaches beyond the selection of an acceptable airborne CAS [79]. A recent FAA study of aircraft separation assurance indicates that the best direction to proceed is with rapid development of DABS and the ground-based Automatic Traffic Advisory Resolution Service (ATARS). When supplemented by an active airborne BCAS, protection of all airspace can be provided. Since it is not expected that national implementation of DABS/ATARS will be completed for some years, a full capacity BCAS designed to operate in all airspace can have an important collision avoidance role, especially during the transition to DABS/ATARS. Thus, CAS appears to be destined for eventual success after a long false start. The main point illustrated by this case history is that if some affected parties are excluded from the initial planning of a complex program, the program may be delayed or require a restart.

D. A Program Doomed to Failure

The final case history is that of AEROSAT, a proposed aeronautical communications/traffic surveillance satellite program which, after ten years of effort, was doomed for failure. Three

papers in Proceedings of the 1974 RTCA Annual Assembly, provide an overview of this program. The first was by David R. Israel [55], then with the FAA, who announced:

> After several years of tentative starts in the late 1960's and after more than three years of detailed and intense discussion and negotiation, we can now announce that AEROSAT has been added to that select group of cooperative international programs in civil aviation. The last signatures to the AEROSAT Memorandum of Understanding, joining together the U.S., Canada and member states of the European Space Research Organization (ESRO), were recorded on August 2 of this year. An initial organizational meeting of signatories was held in Paris on October 10 and 11; residual concerns about French funding and participation were positively resolved in mid-October; and the first formal meeting of the AEROSAT Council will be held in Washington on December 3 and 4.

Mr. Israel went on to discuss the relationship with ICAO:

> The current program, largely following the activities and initiatives of ICAO's ASTRA Panel, represents the principal users and suppliers of air traffic services in the North Atlantic. If AEROSAT is to become the basis of worldwide service, then an even broader base and relationship with ICAO is indicated. The AEROSAT Council expects to open formal relations with ICAO after the first AEROSAT Council meeting in December.

He indicated the following proposed schedule:

> From a schedule point of view, key dates in the selection of the prime contractor for the space segment are expected to be as follows:

Issue RFP:	May 1975
Receipt of Proposals:	July 1975
Selection of Winner:	October 1975
Initiation of Work:	January 1976
First Launch:	mid-1978

However, AEROSAT was cancelled shortly afterwards, as the U.S. Congress refused funding for the project. The reasons for

the refusal can be inferred from two other papers presented at the same conference. A paper by Ben McLeod of Pan American [73] provides some insights into the economics of the program from a potential users' viewpoint:

> Aeronautical satellites have been the goal of over 10 years of study and effort. Today, a pre-operational satellite system is about to become a reality; a Memorandum of Understanding has been signed by ESRO, the U.S., Canada, with COMSAT as the U.S. co-owner. It only remains for the French to approve their share of the funds.
>
> While the airlines last year removed their objection to the FAA AEROSAT program, we have not encouraged this development for several reasons. For a number of years the airlines have recommended a single VHF/L-band hybrid satellite to establish operational and technical system characteristics. After the best features are proven, an operational satellite system could be implemented when needed and projected to be economically desirable.
>
> The current program involving two Atlantic satellites will cost approximately $200 million, or more, over ten years. The U.S. share will exceed $100 million and will be paid from the Aviation Trust Fund.
>
> The international airlines' interest in the program now resides in assuring that R&D funds derived from airline users are well spent, and that a thorough evaluation of VHF and L-band is made. The airlines also wish to participate in the development of future operational recommendations.
>
> We know that we will be asked to pay essentially 100% of the cost of any follow-on operational system, and justifiably we insist on having a strong voice in such an expensive system.
>
> If we are to assume an AEROSAT three-satellite system in the North Atlantic, two for communications and traffic surveillance and one for backup, this single ocean system could cost the airlines $20 million a year. While a global AEROSAT will mean more business to a space industry used to billion dollar figures, to airlines struggling for survival, it could mean economic insanity.

> In summary, we feel that the highest priority should be inter-governmental agreement with user participation, on what steps can be taken to assure that aeronautical satellites will reduce ATC costs - before commitments are made for such costly systems.*

The third paper [2] by John S. Anderson, former President of ARINC, provides additional (political) insight about the AEROSAT program:

> By the mid-1960's, the prospects of replacing the HF oceanic service with a VHF geostationary satellite relay gained serious attention. The goal was a quantum advancement in air-ground-air capabilities worldwide. With access to Syncom, ATS-1, and then ATS-3 through the cooperation of NASA, interested airlines and ARINC, along with equipment manufacturers and others, entered into a data-gathering, system-development period. It became increasingly apparent that early implementation of an operational system was feasible and practical. Negotiation with COMSAT and FAA served to strengthen the optimistic outlook. By mid-1969, plans were being finalized for an operational system by the mid-1970's that would be economical in both frequencies and dollars.
>
> The plan was simply to extend the worldwide, land-based VHF system into the oceanic and inaccessible land areas. In addition to radio spectrum and conservation, the plan offered the far-reaching benefits of employing present techniques and equipments. The progress made during that period is reflected with the VHF satellite antenna an integral part of the Boeing 747 aircraft.

---

*At the 1975 RTCA Assembly, Robert Bohannon of Pan American stated in public commentary [8], "we did a little arithmetic ... and if you use satellites, two of them just over the North Atlantic for air-ground communications and surveillance, such a system could run each flight across the North Atlantic about $300 in cost and charge to the user of that airplane. Today, we are paying somewhere in the order of $150 to cross the Atlantic to four different countries ... . The Canadian Government is charging every airline that crosses the Atlantic and goes through the Gander Flight Information Region, $63. That $63 goes to pay for air traffic control services at Gander and the communication facilities we use there."

But progess was abruptly halted. Apparently, the overseas electronic equipment and satellite manufacturers were riled with not being sufficiently involved in the progress.

An observer not personally involved but well-located and qualified to comment, later described the event as the AEROSAT "debacle." Mr. Oscar Bakke, then stationed in Brussels as FAA Assistant Administrator for Europe, Africa and the Middle East, described what he witnessed:

> "...when the French learned of our plans to launch the AEROSAT in 1972, they expressed considerable consternation not only through editorials and public statements of Government officials, but also in aides memoirs addressed to the Department of State and through a flood of diplomatic notes from other governments which were instigated by the European Space Research Organization (ESRO) at the urging of France."
>
> "Time does not permit a comprehensive analysis of the AEROSAT situation at this time, but it will suffice to say that the French objective was simple: Prevent the U.S. from initiating any satellite effort in VHF. Because they presumed themselves well ahead of the U.S. in L-band technology, they were nationally committed to the requirement for L-band which they concluded would lead to a substantial world requirement for avionics and ground systems, a substantial percentage of which must be provided by French manufacturers... "
>
> "In retrospect, I am still amazed at the tremendous amount of assistance the French obtained from U.S. sources in the pursuit of their strategy. But even more difficult to understand was the national policy adopted by OTP in complete defiance of the U.S. operational requirements which had been agreed between users of the system and the agency charged by law to regulate the users...".

Mr. Anderson continues:

> As viewed from here, OTP had simply entered into some perfunctory discussions or studies and then announced that it would be U.S. policy to "promote the deployment of UHF L-band for satellite relay of oceanic air traffic control communications." Not only were the basic issues of a billion dollar move to L-band handled in an appallingly cavalier manner, but important collateral questions including long-range goals of optimum aeronautical spectrum were admittedly ignored.

> After trying four years to rationalize this thoroughly disruptive OTP action, I recently learned that, based on the evidence, the decision had been VHF. But the decision was reversed, literally overnight, on politics alone.

Mr. Anderson goes on to note that instead of escalating 10-15 percent per year, oceanic communications first leveled off, and at the time of his paper in 1974, it was down 50 percent.* He also noted that digital modernization of existing systems is virtually ready and waiting. It will, he said, increase the information transfer rate, i.e., expand the communications capacity on existing VHF spectrum, by 30:1 in handling digital data, and at the same time accommodate a more efficient radiotelephone service.** (This development may have the effect of delaying further the future need for satellite channels.)

A comparison of these concepts on the same subject from three different perspectives, indicates that any major aviation communications program which is not supported by all the major users and manufacturers is probably doomed to failure.

---

*The period 1970-1974 was quite recessionary for the airlines, resulting from the economic downturn in 1970-1971 and the oil embargo in 1973.

**Many airlines are now making use of the ARINC data link system which serves no ATC function, but rather it is used only for company communications. It is a 2400 bps system and currently takes on approximately 70 percent of the previous voice communications load automatically. The data link fits nicely into modern aircraft architecture by directly connecting the plane digitally with ground-based communications and data processing capabilities [16].

III. General Observations

This section will make some general observations relative to evolutionary technological changes to smaller aviation communication systems followed by observations related to the ingredients needed for the successful introduction of new large-scale systems.

It has been pointed out [16] that the basic philosophies underlying aviation communication systems for navigation and air traffic control have remained relatively unchanged over the past 40 years while the technologies supporting these philosophies have changed in an evolutionary manner. In communications, there was the change from LF and HF to the 2400 bps air-ground-air-data link. In navigation, 40 years ago there was the 4-course LF range. The only major improvement since then was the adoption of VOR and DME, together with ILS. ADF (Automatic Direction Finders) was introduced in 1935 and is still one of the most used aids. There has been the more recent introduction of "self-contained" aids such as doppler radar, radio altimeters and inertial navigators, but these are used by a relatively small number of aircraft. In air traffic control, its most important function, the avoidance of collisions, is still handled by controllers on the ground. The major improvement has been the addition of radar surveillance, together with a greater degree of automation.

Although these functions can be performed by electron tube circuitry, in the newer systems they are being performed more reliably, with considerably less weight, space, power and maintenance, by semiconductor devices and digital circuitry. A change in display technology from bulky cathode ray tubes (CRTs) to flat panel displays is also underway.

These evolutionary changes are all readily accepted by general aviation and the carriers for the reasons previously mentioned. From time to time, however, the government imposes new safety equipment: Emergency Locator Transmitters (ELT) for general aviation (under Public Law 91-596*), crash recorders and the Ground Proximity Warning System (GPWS) for the carriers. Long-term development programs were unnecessary as most of this equipment made use of current technology; however, complaints were heard concerning the outlays required for compliance. Industry specifications can do much to reduce costs. For example, when GPWS was first introduced in September 1974, the price was $6,000. By March 1975, the price dropped to about $3,000 as the result of competition to a standard design [1].

*In 1976 there were more than 135,000 ELT's in use. Considerable problems were encountered with false alarms, mechanical, electronic, installation and monitoring. RTCA subcommittees SC-127 and SC-136 are preparing proposals for coping with these problems.

For the larger aviation communication systems, the case histories presented in the previous section suggest that the following factors can affect the speed of technology innovation and diffusion [16]:

1. <u>Independence of Usage</u>

   Innovation and diffusion are rapid when the new technology can be used on aircraft without the need for a new ground environment (e.g., automatic direction finder, doppler radar, and inertial navigation), or can be used on the ground without requiring every aircraft to have some new equipment (e.g., ATC automation).

2. <u>Compatability</u>

   Innovation and diffusion are rapid when the new technology is compatible with current and past practices and systems, and system redesign is unnecessary for full utilization. Examples of fast diffusion include: VOR, DME and ILS. Counterexamples of slow diffusion include: Hyperbolic systems and ATCRBS.

3. <u>Cost Threshold</u>

   Innovation and diffusion are rapid when a few aircraft or users can benefit tangibly after the new technology is applied to one small area, rather than waiting for universal installation before anybody benefits. Examples include: VOR, DME and ILS.

4. Vulnerability

Innovation and diffusion are slow when the new technology is vulnerable to potential enemy threat. Examples include: Ground-based line-of-sight systems and satellite-based systems.

5. Identification of Users

Innovation and diffusion are rapid when users or beneficiaries can be clearly identified. "Spin-off" arguments work slowly or do not work at all. The longer it has been talked about, without action, the more likely that the new technology will die of obsolescence before it is ever tried.

What are the ingredients of a successful large-scale program? Using MLS as a model, it appears that such a program would consist of the following elements:

1. Identification of the need for a specific system. Very often, this will come from an industry association or from within the FAA itself.
2. Exploratory research indicating the possibility of a feasible solution. Experience has shown that it is preferable to obtain involvement of all classes of users, potential equipment manufacturers with national and international representation. In the case of MLS more than three years was required from the ATA letter

that initiated the program in late 1967 to the publication of the RTCA SC-117 report in December 1970 that defined the system concept and formed the basis for a fully coordinated National Plan for MLS in 1971.

3. Budgetary planning timely introduction. As previously pointed out, seven to nine years is required to get through the normal FAA budgeting and contracting cycle.
4. Project Management team established. This team must establish an on-going consultative process with all interested parties as did the MLS team. This process requires constant coordination within the FAA, DOT, Congress, GAO, OMB, and other involved agencies.
5. Systems engineering and program management procedures implemented. Systems engineering and program management techniques for the development and implementation of large-scale systems are well known within government and industry. System engineering has three major dimensions. The time dimension includes the phases that extend from the initial conception of an idea through system retirement. The logic dimension deals with the steps that are carried out at each of the phases. The knowledge dimension refers to the specialized knowledge needed from the various professions and disciplines. These are the dimensions of the Hall Morphological Box concept of systems engineering [51 and 52].

6. Production in industry according to national and international standards and specifications. This is the key to the successful deployment of a new system. IACO standards are used by Governments to meet their international obligations, to provide required services and to approve equipment used in aircraft [74]. RTCA committees develop "Minimum Operational Performance Standards" which form frequently the basis for the FAA's "Technical Standard Orders (TSOs) which have the force of law. ARINC, through its Airline Electronic Equipment Committee (AEEC) develops the ARINC specifications which provide assurance of "fit, form and function" permitting interchangeability of older systems with newer ones, and from one manufacturer to another, resulting in substantial cost savings.

While these elements appear rational and straightforward enough to be followed by any major aviation communication system planning and coordination effort, in reality many diverse social, economic, and political forces come into play. What may be derived from the case histories of use for the technology forecasts in Phase III of this project are the following orders of time lags in the adoption of new aviation communication systems.

1. The smooth introduction of new major aviation communication systems may take 12 to 15 years between the time of

initial development of requirements and the time of first operation. MLS provides a good example.

2. The smooth introduction of small scale systems may be as short as 1 to 2 years, especially if the system uses off-the-shelf technology, does not require air-ground equipment coordination, and is not mandatory for all aircraft. GPWS provides such an example.
3. A false start may substantially lengthen the time for introducing major aviation communication systems. Problems become complicated especially when the system requires air-ground equipment coordination, or is mandatory for all aircraft (especially GA), or involves international negotiations. Thus, in the case of CAS, the time lag has about doubled, and in the case of AEROSTAT, the time lag seems to have become infinite.

The above three generalizations refer primarily to RCS, in which technology diffusion tends to go directly from the electronics industry to the aviation communications industry. In the VCS and DCS cases, the technology tends to follow that used in the Bell System. The Bell System is often 3 to 5 years behind the smaller avant garde companies, since the latter operate smaller systems and thus have less invested capital to depreciate.

CHAPTER FIVE

CONCLUSIONS

Any serious technology forecast and assessment study must begin with an understanding of the past and current status and trends of the particular technological field and its environment. The environment includes the sources from which the basic technological knowledge evolves, the changing needs to be met by the technological applications, and the major forces which govern the dynamic process of technological innovation and diffusion. This initial task has been completed in Phase I of this study.

In this volume, the changing role of communications in aviation has been traced from the days of the Wright Brothers to the present. Current aviation communication systems have been classified into three categories, namely Radio Communications System (RCS), Voice Communications System (VCS), and Data Communications System (DCS). The existing equipment and subsystems currently in the Air Traffic Control System, within each of these three categories, have been described. Proposed changes to the aviation communication system have been reviewed and provide clues as to the new features which will likely be incorporated into the aviation communications system by 1985. This near-term forecast and the description of the present system provide the basis for the longer-term forecast to 2020 A.D. to be completed in Phase III of the study.

Long-range forecasts and assessments of technologies are needed in developing proactive policies which anticipate technological changes and thereby maximize their potential benefit. Development of long-range forecasts for communications technologies is risky, however, not only because of the potential for rapid change but because of the difficulty of forecasting governmental regulations. In attempting to avoid both overly optimistic or pessimistic forecasts, several case histories of technology innovation and diffusion in aviation communications have been reviewed, including both successfully and unsuccessfully implemented innovations. An attempt has been made to generalize the influence on the speed of innovation and diffusion of a number of factors, such as the involvement of air-ground equipment coordination, governmental planning acquisition and regulation, cost and performance thresholds, air carrier and GA involvement, and international acceptance and standardization.

Phase II of the study, the construction of several alternative scenarios, will provide the context for the long-range forecast and assessment of aviation communications systems to circa 2020 A.D. The set of alternative aviation futures which has been used for FAA's aviation activities forecast [31] will be used as a point of departure and will be expanded in two directions. First, the time horizon will be extended from 1990 to 2020 A.D. In this

extension, broader changes in socioeconomic conditions will be assumed than those considered plausible within the shorter time horizon of 1990. Second, scenario variables will be expanded to include demographic variables and the regulatory climate, which are not a part of the current FAA forecasts. The variables which will be added will include those which have been found in Phase I to be significant for realistic technology forecasts.

Work has also begun in Phase III to develop an overview of the basic electronics technologies to be forecasted, taking into account the categorization and diversity of aviation communication systems described in this report. The assumptions for these unconditioned technology forecasts parallel the specification of aggregate variables in the alternative future scenarios. Thus the unconditioned forecasts will be amenable to modification as a result of the scenario forecasts. These conditioned technology forecasts will form the foundation for the aviation impact assessments of Phase IV and the identification of policy options in Phase V of this study.

GLOSSARY

ACAS	Airborne Collision Avoidance System
ADF	Automatic Direction Finder
ADIS	Automatic Data Interchange System
ADS	Alpha-numeric Display System
AFS	Aeronautical Fixed Service
AFTN	Aeronautical Fixed Telecommunications Network
AID	Airport Information Desk
AIREP	Air Report
ALS	Approach Lighting System
AMIS	Aircraft Movement Information Service
API	Air Position Indicator
ARINC	Aeronautical Radio, Inc.
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
ASR	Airport Surveillance Radar
ATA	Air Transport Association
ATARS	Automatic Traffic Advisory Resolution Service
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATCSCC	ATC Systems Command Center
ATCT	Airport Traffic Control Tower
ATIS	Automatic Terminal Information Service
BASOPS	Military Base Operations
BCAS	Beacon Collision Avoidance System
BUEC	Backup Emergency Communications
CAS	Collision Avoidance System
CCC	Central Computer Complex
COMSAT	Communications Satellite Corporation
CRT	Cathode-Ray Tube
CST	Combined Station/Tower
DABS	Discrete Address Beacon System
DCS	Data Communication System
DF	Direction Finder
DME	Distance Measuring Equipment
EFAS	En Route Flight Advisory Service
EPI	Expanded Position Indicator
ESS	Electronic Switching Systems
EVSS	Electronic Voice Switching System

FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FAWS	Flight Advisory Weather Service
FDEP	Flight Data Entry and Printout Equipment
FDP	Flight Data Processing
FIPS	Federal Information Processing Standard
FSS	Flight Service Station
GA	General Aviation
GPWS	Ground Proximity Warning System
HDTA	High Density Terminal Area
HF	High Frequency
Hz	Hertz (cycles per second)
IC	Intercom
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IFSS	International Flight Service Station
ILS	Instrument Landing System
IP	Interphone
ISLS	Improved Sidelobe Suppression
KHz	Kilohertz
LF	Low Frequency
LINS	Laser Inertial Navigation System
LPLO	Limited Range Communication Outlet
LRR	Long-Range Radar
MF	Medium Frequency
MFS	Military Flight Service
MHz	Megahertz
MLS	Microwave Landing System
MSAW	Minimum Safe Altitude Warning System
MWTCS	Modernized Weather Teletypewriter Communication Service
NAFEC	National Aviation Facilities Experimental Center
NADIN	National Airspace Data Interchange Network
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCOM	National Communications Center
NAVAID	Air Navigation Facility
NFDC	National Flight Data Center
NOTAM	Notice to Airmen

PARWAS	Pilot Automatic Transcribed Weather Answering Service
PIREP	Pilot Report
RAPCON	Radar Approach Control
RATCF	Radar Air Traffic Control Facility
RCS	Radio Communication System
RCCS	Radio Communication Control System
RCTA	Radio Technical Commission for Aeronautics
RFP	Request for Proposal
RTR	Remote Transmitter/Receiver Facility
RMM	Remote Maintenance Monitoring
RCAG	Remote Center Air/Ground Communication Facility
RCO	Remote Communications Outlet
RML	Radar Microwave Link
RNAV	Area Navigation
SAR	Search and Rescue
SECRA	Secondary Radar
SFO	Single Frequency Outlet
SLS	Sidelobe Suppression Beam
SPAN	Stored Program Alpha-Numeric Project
S/R	Send/Receive
SSF	System Support Facility
SVSS	Small Voice Switching System
TACAN	Tactical Air Navigation
TELCO	Telephone Company
TDP	Technical Data Package
TRACON	Terminal Radar Approach Control
TRSB	Time Reference Scanning Beacon
TWEB	Transcribed Weather Broadcast Service
UHF	Ultra High Frequency
VCS	Voice Communication System
VF	Voice Frequencies
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	Very High Frequency Omnidirectional Range
VORTAC	(see VOR and TACAN)
VSCS	Voice Switching Control System
WATS	Wide Area Telephone Service
WECO	Western Electric Company
WMSC	Weather Message Switching Center

REFERENCES

1. AEEC Letter N77-126/AXX-00, dated November 25, 1977, Aeronautical Radio, Inc.

2. Anderson, John S., "Aviation's Stake in the Electromagnetic Spectrum", Proceedings, 1974 RTCA Annual Assembly.

3. ARINC HF SSB Long Distance Operational Control Facility, Description of Service and Operating Procedures, Aeronautical Radio, Inc., Annapolis, Maryland, March 1976.

4. ARINC, Air-Ground Radio Telephone Stations, International Service, Aeronautical Radio, Inc., Annapolis, Maryland, December, 1977.

5. Ayres, Robert U., Technological Forecasting and Long-Range Planning, McGraw-Hill, 1969.

6. Batelle Columbus Laboratory and University of Michigan, "An Integrated Assessment of Coal-Based Energy Technology" (First Annual Report), U.S. Environmental Protection Agency, 1979.

7. Bell, Daniel, The Coming of Post-Industrial Society, Basic Books, 1973.

8. Bohannon, Robert, Comments (Audience Participation), Proceedings, 1975 RTCA Annual Assembly, p.E-48.

9. Bowers, Raymond et al. (ed.), Communications for a Mobile Society: An Assessment of New Technology, Sage, 1978

10. FAA Historical Fact Book, A Chronology 1926-1971, Arnold E. Briddon, Ellmore A. Champie, and Peter A. Marraine, DOT/FAA Office of Information Services, 1974.

11. Carnes, William T., "Tenth Anniversary Chronology of AEEC", Aeronautical Radio, Inc.

12. Chen, Kan et al., "Value-Oriented Social Decision Analysis", a research proposal by the University of Michigan, accepted by the National Science Foundation, 1977.

13. Computer Sciences Corporation, FAA Communications System Description (1973), FAA Report No. FAA-RD-73-36, February 1973.

14. Del Balzo, Joseph, "Concept to Implementation - Why Does It Take So Long?", Proceedings, 1976 RTCA Annual Assembly.

15. Department of Transportation/Department of Commerce/Department of Defense/National Aeronautics and Space Administration, Transportation Telecommunications Planning, Transportation Telecommunications Steering Group, August 1974.

16. Dodington, Sven "Observations on the Application of Technology to Airspace Management During the Past Forty Years and the Decades Ahead", Proceedings, 1977 RTCA Annual Assembly.

17. Edwards, Norman R., "Air Traffic Control System, Evolution and Automation (U.S. Trend).", Proceedings of the 1975 Annual Assembly Meeting, Radio Technical Commission for Aeronautics, November 18-19, 1975.

18. Edwards, Norman, "Air Traffic Control System Evolution and Automation", Proceedings, 1975 RTCA Assembly.

19. Edwards, Norman R, Air Traffic Control System Evolution and Automation (U.S. Trend), FAA/SRDS Acting Deputy Director, Proceeding of the 1975 Annual Assembly Meeting, Radio Technical Commission for Aeronautics, Washington, D.C., November 18-19, 1975.

20. Feinman, Stephen and William Fuentevilla, "Indicators of International Trends in Technological Innovation", National Science Foundation (NSF-SIU-76-1), 1976.

21. FAA, "Consultative Planning Conference: New Engineering and Development Initiatives -- Policy & Technology Choices", March 22-23, 1978.

22. FAA, "The Impact of Microcomputers on Aviation" A Technology Forecasting and Assessment Study", (two volumes), DOT FA76WAI-609, September, 1977.

23. FAA, "Voice Switching and Control System (VSCS) Requirements", FAA/ARD-22- Draft, September 28, 1978.

24. FAA, Engineering and Development Program Plan, Flight Service Station Automation Program, FAA-ED-13-1A, April, 1978.

25. FAA, Preliminary Integrated Communications Concept and Implementation Plan (Draft), submitted as Task I(c), Contract No DOT-FA78WAI-830.

26. FAA, System Research and Development Service Progress Report, Washington, D.C., U.S. DOT/FAA, Autust 8-9, 1978.

27. FAA, Engineering and Development Program Plan, Flight Service Station Automation Program, Document FAA-ED-13-1A, April 1978, DOT/FAA SRDS, Washington, D.C.

28. FAA, A Proposal for the Future of Flight Service Stations, Vol. I, Flight Service Station Evaluation Team, U.S. DOT, Autust 1973, Washington, D.C.

29. FAA, AAT-140 Program Status Report, September/October 1978, Prepared by AAT-140, DOT/FAA, November 13, 1978.

30. FAA, "The Impact of Microcomputers on Aviation: A Technology Forecasting and Assessment Study", (two volumes), DOT/FA 76WAI-609, September 1977.

31. FAA, "Aviation Forecasts Fiscal Years 1979-1990", September 1978, FAA-AVP-78-11.

32. FAA, Airway Facilities Sector Level Staffing Standard System, Order 1380.40, December 8, 1976.

33. FAA, ATS Fact Book, DOT/FAA Flight Services Division, Air Traffic Service, June 30, 1978.

34. FAA, Voice Switching and Control System (VSCS) Requirements, DOT/FAA (Draft Report, ARD-200, September 1978).

35. FAA, Preliminary System Design Report for the Voice Switching and Control System (Draft), Contract NOT FA78WAI-830, October 10, 1978.

36. FAA, Combined Radio Communications Control System (RCCS) and Voice Communications System (VCS) Study, Contract No. DOT-FA78WAI, June 1978.

37. FAA, Preliminary Integrated Communications Concept and Implementation Plan (Draft), Contract DOT FA78WAI-830, October 10, 1978.

38. FAA, National Airspace Data Interchange Network (NADIN) Specification, DOT/FAA, FAA Document No. FAA-E-2661, January 1977.

39. FAA, Report on the Evaluation of Remote Maintenance Monitoring; Hutchinson, Kansas RCAG Facility, Report ACE-AF-78-3, March 6, 1978, DOT/FAA Central Region, A. F. Division, Kansas City, Mo.

40. FAA, Interface Control Document (ICD) for the Remote Maintenance Monitoring System (RMMS), Draft, FAA, September 25, 1978.

41. FAA, Remote Maintenance Monitoring System Level II Interface Control Document (ICD) Guidelines - Draft--For Review only, DOT/FAA, September 1978.

42. FAA, NAS Indoctrination of Engineers and Technicians, FAA Academy Catelog No. 44403, DOT/FAA.

43. FAA, Integrated National Airspace Communications System (INACS) for the Support of Air Traffic Control Operations in the 1980s and 1990s, Operational/Maintenance Requirements, FAA-INACS-061-221-OR, DOT/FAA/SRDS July 11, 1975.

44. Freer, Duane W., "Policy Issues and Economic Alternatives", March 22-23, 1978.

45. Gilbert, Glen A., Air Traffic Control: The Uncrowded Sky, Washington, D.C., Smithsonian Institution Press, 1973.

46. Gilbert, Glen A., Air Traffic Control: Speeches, Interviews, Studies, Technical Papers, 1967-1971.

47. Gilbert, Glen A., ATC-How It All Began, Intervals, 1967.

48. Goldsborough, Paul (ARINC President), in an FCC hearing in June 1936.

49. GRM Corporation, Air Traffic Radio Channel Control Specification Sheets, ARTCC-800 System and ARTCC-2400 System.

50. Gumina, Leo V., Voice Switching and Control System for FAA Voice Communications, Systems Research and Development Service Progress Report, August 8-9, 1978, FAA-RD-78-90, U.S. DOT/FAA, Washington, D.C.

51. Hall, Arthur D., A Methodology for Systems Engineering", Van Nostrand, Princeton, 1962.

52. Hall, Arthur D., "A Three Dimensional Morphology of Systems Engineering", IEEE G-SSC Transactions, April, 1969.

53. Hansen, J.C. et al., "FAA Communication System Description 1973", FAA-RL-73-36, February 1973.

54. Honeywell Systems and Research Center, RCAG Performance Monitoring System, Operation and Maintenance Manual, Minneapolis, Minnesota, July 1977.

55. Israel, David R., "International Cooperation in the Aerostat Program", Proceedings, 1974 RTCA Annual Assembly.

56. Israel, David R., "Air Traffic Control: Upgrading the Third Generation", Technology Review, January 1975.

57. AMAF Industries, Inc., National Airspace System (NAS) Communications-State of the Art Description, Draft, ART-001-78 December 15, 1978

58. Jackson, William, Federal Airways System, IEEE Press, 1970.

59. Jensen, Walter, "National Airspace System Implementation - Order or Chaos?" Proceedings, 1978 RTCA Assembly.

60. Jordenoff, Through the Overcast, Funk and Wagnell Co., 1938.

61. Kahn, Alfred, "Route Awards and Airline Scheduling Practices" March 22-23, 1978.

62. Kelly, Robert, Henry Redlian, and Jack Shagena, "Landing Aircraft Under Poor Conditions", IEEE Spectrum, September 1978. (An excellent technical description of MLS).

63. Kingsley, A.K., National Airspace Data Interchange Network (NADIN), FAA Report No. FAA-RD-78-90.

64. Koenke, E.J. et al., "FAA BCAS Concept - Executive Summary", FAA Office of System Engineering Management, FAA Report EM-78-5I, April 1978.

65. Lapp, Ralph, The Logarithmic Century, Prentice-Hall, 1973.

66. Linstone, Harold A. et al., "The Use of Structural Modeling for Technology Assessment" (2 volumes", Portland State University, February 1978.

67. Litchford, G.B., Avoiding Midair Collisions, IEEE Spectrum, September 1975.

68. Litton, Amecom, Terminal Communications Switching System, Section 1, Systems Description, DOT Contract No. FA7 2WA-2948, AMECOM document AM011-0001(098), January 1976.

69. Martin, James, Telecommunications and the Computer, 2nd edition, p.654, Prentice-Hall, 1976.

70. Martin, James, Future Developments in Telecommunications, 2nd edition, p.22, Prentice-Hall, 1977.

71. Martin, James, Future Developments in Telecommunications, 2nd edition, p.159, Prentice-Hall, 1977.

72. Matthews, Mark, "Laser Inertial Navigator to be Tested", IACO Bulletin, March 1978.

73. McLeod, Ben, "Management Views on Major Issues Facing the Airlines", Proceedings, 1974 RTCA Annual Assembly.

74. McWiggan, Thomas J., "International Aspects of Standardization", Proceedings, 1978 Annual Assembly.

75. Meyers, S. and D Marquis, Successful Industrial Innovations, National Science Foundation, 1969.

76. MITRE Corporation/METREK Division, Survey of Small Key Telephone Systems, FAA Project No. 1414B/DOT FA78 WA-4075, April 1978.

77. National Science Foundation, The Process of Technological Innovation, 1969.

78. Porat, Marc, The Information Economy, Stanford University, 1976, and Government Printing Office, 1976.

79. Poritzky, Siegbert B., "FAA Air Traffic Control and Automation - Programs and Trends", Proceedings, 1978 RTCA Annual Proceedings.

80. Radio Technical Commission for Aeronautics, The Terminal Area and Its Environs, opening remarks of the moderator Vernon I. Weihe, Proceedings of the 1975 Annual Assembly Meeting, Washington, D.C., November 18-19, 1975.

81. Radio Technical Commission for Aeronautics, Navigation and Landing Guidance, Proceeding of the 1975 Annual Assembly Meeting, November 18-19, 1975, Washington, D.C.

82. Radio Technical Commission for Aeronautics, Air-Ground Communications-Operational Considerations for 1980 and Beyond, Document No. DO-162, Washington, D.C., October 17, 1975.

83. Robert, Louis W. et al., "FAA Communication System Description, 1973", FAA-RL-73-36, February 1973.

84. Robinson, Glen O. (ed.), Communications for Tomorrow: Policy Perspectives for the 1980s, Praeger, 1978.

85. Rogers, Everett, Diffusion of Innovations, The Free Press, New York, 1962.

86. Proceedings, 1976 RTCA Annual Assembly.

87. Proceedings 1978 RTCA Annual Assembly.

88. RTCA, "Air Ground Communications -- Operational Considerations for 1980 and Beyond", SC-120, 1975.

89. RTCA, "Air Ground Communications -- Operational Considerations for 1980 and Beyond", RTCA Document DO-162, October 17, 1975.

90. RTCA, "Air Ground Communications -- Operational Considerations for 1980 and Beyond", SC-120, October 17, 1975.

91. Steele, Nate, "Impact of Technological Improvements in Air-Ground Communications", Proceedings, 1977 RTCA Annual Assembly.

92. Theberge, N., The Impact of a Proposed Active BCAS on ATCRBS Performance in Washington, D.C., 1981 Environment, Report No. FAA-RD-77-140, DOT/FAA, September 1977.

93. Tilton, John, International Diffusion of Technology: The Case of Semiconductors, Brookings Institution, 1971.

94. Verve Research Corporation, Study Requirements for an Integrated Air/Ground Communications Facility, FAA Report No. FAA-RD-76-154, May 1977.

95. Weihe, Vernon I., "The Terminal Area and Its Environs", Proceedings of 1975 Annual Assembly Meeting, RTCA, November 18-19, 1975.

96. White, Frank, "Where Does Aircraft Separation Assurance (or CAS) Now Stand? - A Historical Perspective", Proceedings 1978 RTCA Annual Assembly.

97. Wulfsberg, Arthur, "Management to the Rescue", IEEE Spectrum, p.76, October 1978.

98. Zaltman, Gerald, Robert Duncan and Jonny Holbek, Innovations and Organizations, John Wiley, 1973.